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SPINAL INJURY AFTER EJECTION

R. Auffret and R.P. Delahaye

Translation of "Lesions Vertebrales apres Ejection," Laboratoire de Medecine Aerospatiale, Centre d'Essais en Vol, AGARD-ASMP Working Group on Spinal Injury after Ejection, Report, May 1974, 99 pp.

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16. Abstract Ejection statistics obtained from the air forces of seven nations are analyzed, including figures on the incidence of death, the incidence of fracture and multiple fractures, and preferential fracture sites. A basic review of the anatomy of the spine is followed by a discussion of the mechanics of spinal fracture. It is difficult to determine the stage of ejection at which fractures are most likely to occur -- expulsion from the aircraft or landing -- but the position of the pilot at the moment of ejection is considered to be of prime importance. A study of x-ray procedure deals in detail with the appearance of spinal fractures of varying degree and the characteristics distinguishing them from congenital abnormalities or the effects of disease. Treatment procedure is reviewed and the systematic use of x-ray examination is recommended. Finally, current standards for aircrew fitness are discussed, with the conclusion that in general, these criteria are excessively strict.

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Foreword

The working group "Spinal injury after ejection: Mechanism, diagnosis and surveillance" was created by the Aerospace Medicine Group of the AGARD (Advisory Group for Aerospace Research and Development) at the end of 1971. It is participating in the research requested by the ASMP/"Biodynamic Committee" headed by Dr. W.L. Jones, Deputy NASA Director.

This research report represents a synthesis of current information on spinal injury after ejection. Its preparation has been facilitated by the receipt of foreign documents written in response to the questionnaire/work plan proposed by the French coordinators and accepted at the AGARD/ASMP meeting of September 4, 1972, in Glasgow.

We would like to thank the various participants in the working group for the effectiveness of their aid.

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CHAPTER I. STATISTICAL STUDY OF EJECTIONS /1*

This analysis deals only with modern flight seats. A single release mechanism (an actuator in a high or low position, the armrests) triggers the automatic operation of the entire ejection sequence. Previous ejection systems with non-automatic seats, which are no longer used, offer only historical interest.

Table I summarizes the overall ejection results obtained by the organizations which responded to the questionnaire sent out by the Working Group. In cases where the entries are marked only with an "x" no information was available (RAF, HAF). Standard NATO abbreviations are used for the organizations.

FAF = French Air Force
GAF = German Air Force
HAF = Hellenic Air Force
IAF = Italian Air Force
RAF = Royal Air Force

Table I includes two totals:

-- total No. 1 corresponds to all the information for all headings (USAF, U.S. Army, FAF, GAF, IAF).

-- total No. 2 indicates the number of pilots with spinal fractures and the total number of spinal fractures observed in the organizations responding (USAF, U.S. Army, FAF, GAF, HAF, IAF and RAF).

Table II combines two types of data which seem to us to be significant:

-- the percentage of deaths in relation to the total number of ejections,

-- the percentage of surviving pilots with spinal fractures in relation to the total number of survivors.

*Numbers in the margins indicate pagination in the foreign text.

TABLE I. OVERALL RESULTS: U.S. Air Force (Col. F. Barnum), U.S. Army (Drs. Kaplan and Braunoler), FAF (Lt-Col. Auffret and Col. Delahaye), GAF (Lt-Col. Beck, Drs. Gapel and Rieder), HAF (Lt-Col. Simeonides), IAF (Col. C. Rotondo), RAF (Air Com. Griffin).

	Number of Ejections	Death	Successful Ejection	Number of Pilots with One Spinal Fracture	Number of Spinal Fractures
U.S. AIR FORCE	213	45	168	17	33
U.S. ARMY	91	13	78	26	39
F.A.F.	103	11	92	20	29
G.A.F.	171	34	137	14	24
H.A.F.	x	x	x	6	12
I.A.F.	100	11	89	15	27
R.A.F.	x	x	68	32	57
TOTAL 1 :	678	114	564	92	152
TOTAL 2 :	–	–	–	130	216

TABLE II.

	Total Number of Ejections	% Death	Pilots with Spinal Fractures, % (as a Function of Number of Survivors)
U.S.A.F.	213	21,1	10,1
U.S. ARMY	91	14,50	34,3
F.A.F.	103	10,6	21,7
G.A.F.	171	19,3	10,2
I.A.F.	100	11	16,8
R.A.F.	x	x	47

An examination of Tables I and II shows that deaths are most frequent in the USAF and GAF statistics. On the other hand, the frequency of fractures is higher for pilots in the IAF, FAF and especially the U.S. Army.

These data permit a discussion of the existence of a possible relationship between the number of fractures and the number of deaths. In cases where there were a high number of fractures, there were few deaths, and where there were a large number of deaths, there were few fractures. This overall impression perhaps merits more careful attention; however the information received does not permit precise formulation of an explanatory hypothesis.

Spinal fractures after ejection, even with the use of modern seats, remain the most frequently encountered injuries (10 to 47% of surviving pilots according to the armed forces concerned). Study of these injuries continues, and an effort should be made to implement all possible methods to decrease this high percentage.

TABLE III. DISTRIBUTION OF FRACTURES.

Vertebra	USAF	U.S. Army	F.A.F.	G.A.F.	H.A.F.	I.A.F.	R.A.F.	TOTAL	Observations.
C_1	–	–	–	–	–	–	1	1	
C_4	–	–	–	1				1	
C_5	1			1			1	3	
C_6	1			1				2	
C_7	1							1	
D_3	1		1	1			1	4	
D_4	1	1		3			1	6	
D_5	2	3	3	3			2	13	
D_6	1	3	2	1			2	9	
D_7	3	2	2	2		1	1	11	
D_8	1	6	3	2		2	3	17	
D_9	–	2	–	–		1	7	10	
D_{10}	–	2		1	1		7	11	
D_{11}	2			1	2	2	9	16	
D_{12}	6	3	3	2	3	7	12	36	

[Table continued on following page.]

Table III [continued]

Vertebra	USAF	U.S. Army	FAF	GAF	HAF	IAF	RAF	TOTAL	Observations
L_1	7	6	11	4	5	5	8	46	
L_2	1	3	3		1	1	2	11	
L_3	1			1		2		4	
L_4	1	1	1			2		5	
L_5	1							1	
SACRUM	1							1	
VARIOUS & UNKNOWN	1	7						8	
TOTAL FRACTURES	33	39	29	24	12	23	57	217	
NUMBER OF PILOTS	17	26	20	14	6	15	32	130	

Table III shows the distribution of fractures by vertebra. /5
An examination of the corresponding curve shows that there is:

-- a marked peak at the level of D_{12}-L_1 (37°C at the site);

-- a high frequency of fractures of the dorsal column (more than half of the total number of spinal fractures after ejection).

These findings corroborate the data collected through examination of statistics on traumatic accidents in civil practice (public throughways and transportation, occupational or sports accidents). In investigating these ejections it has been difficult, if not impossible, to determine the time when the fracture of the spinal column occurs, either upon leaving the ejectable seat or upon reaching the ground. It has been possible, however, for us to compare two sets of statistics:

1. Ejection statistics from the NATO Armed Forces, which include fractures occurring upon ejection of the seat and upon landing (Fig. 1).

2. Statistics on fractures incurred by airborne troops of the French Army, involving 1,181,155 jumps (195 fractures) (see Fig. 2).

From a rough comparison of the two curves it appears certain that the acceleration of the seat as it is ejected is capable of resulting in the occurrence of fractures distributed over the entire dorsal and lumbar areas. On the other hand, in trauma incurred in parachute operations, the fractures occur predominantly at the level of the single dorsolumbar hinge. Specific observations on several fracture sites will be dealt with in Chapter II, on pathogeny.

Multiple fractures (Table IV) frequently occur in ejected pilots (40 pilots in 92, that is, 40.8%), with a virtually identical distribution in the USAF, the FAF, the GAF and the RAF. It should be noted that a multiple fracture of the spinal column does not necessarily constitute a serious factor here. The energy absorbed is distributed over several vertebrae which show less severe injuries than if only one vertebra had been fractured. This finding does not seem to be a universal rule, however.

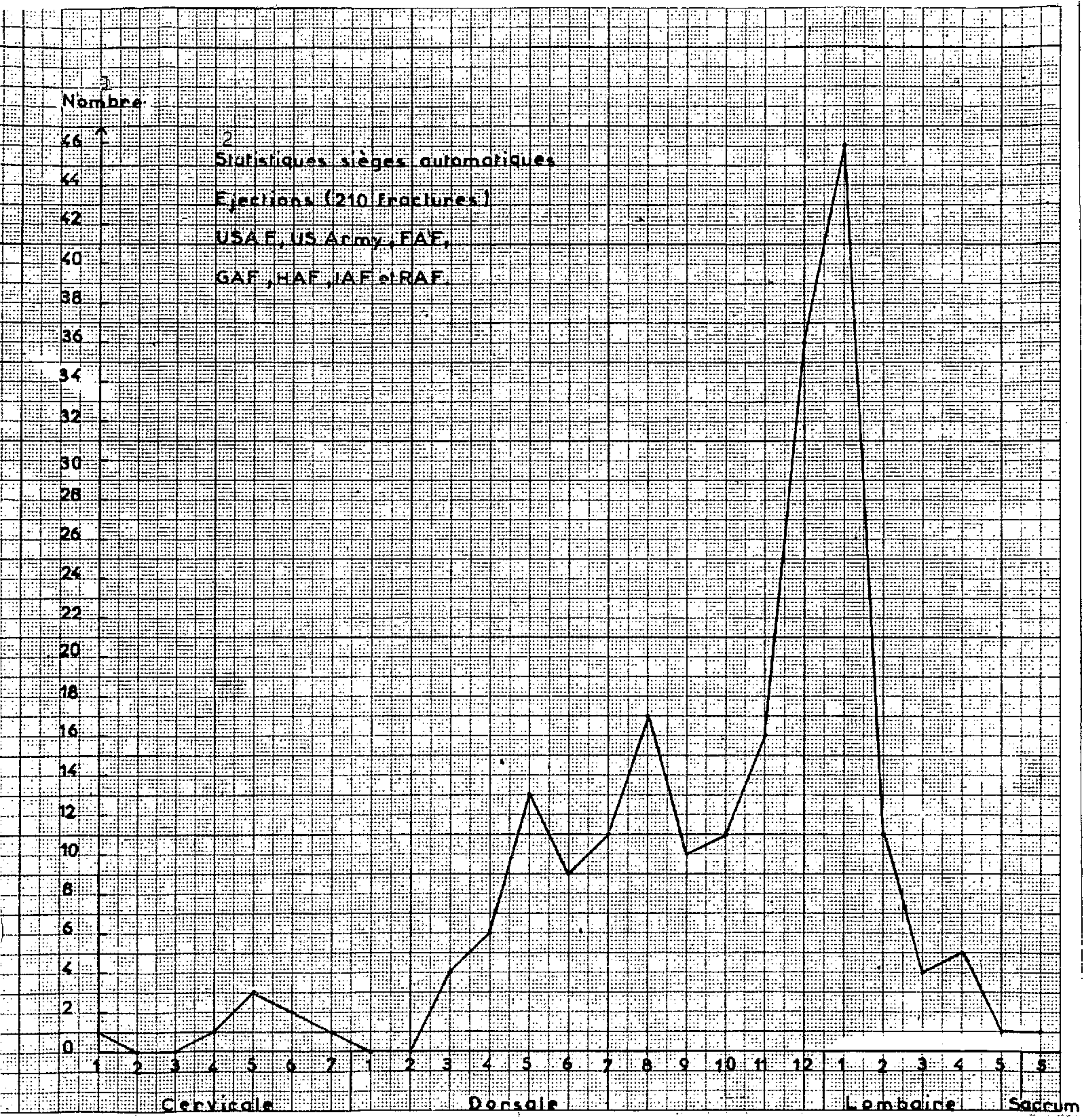

Fig. 1. Statistics on ejections studied (210 fractures): USAF, U.S. Army, FAF, GAF, HAF, IAF, and RAF.

Key: 1. Number; 2. statistics on automatic seats

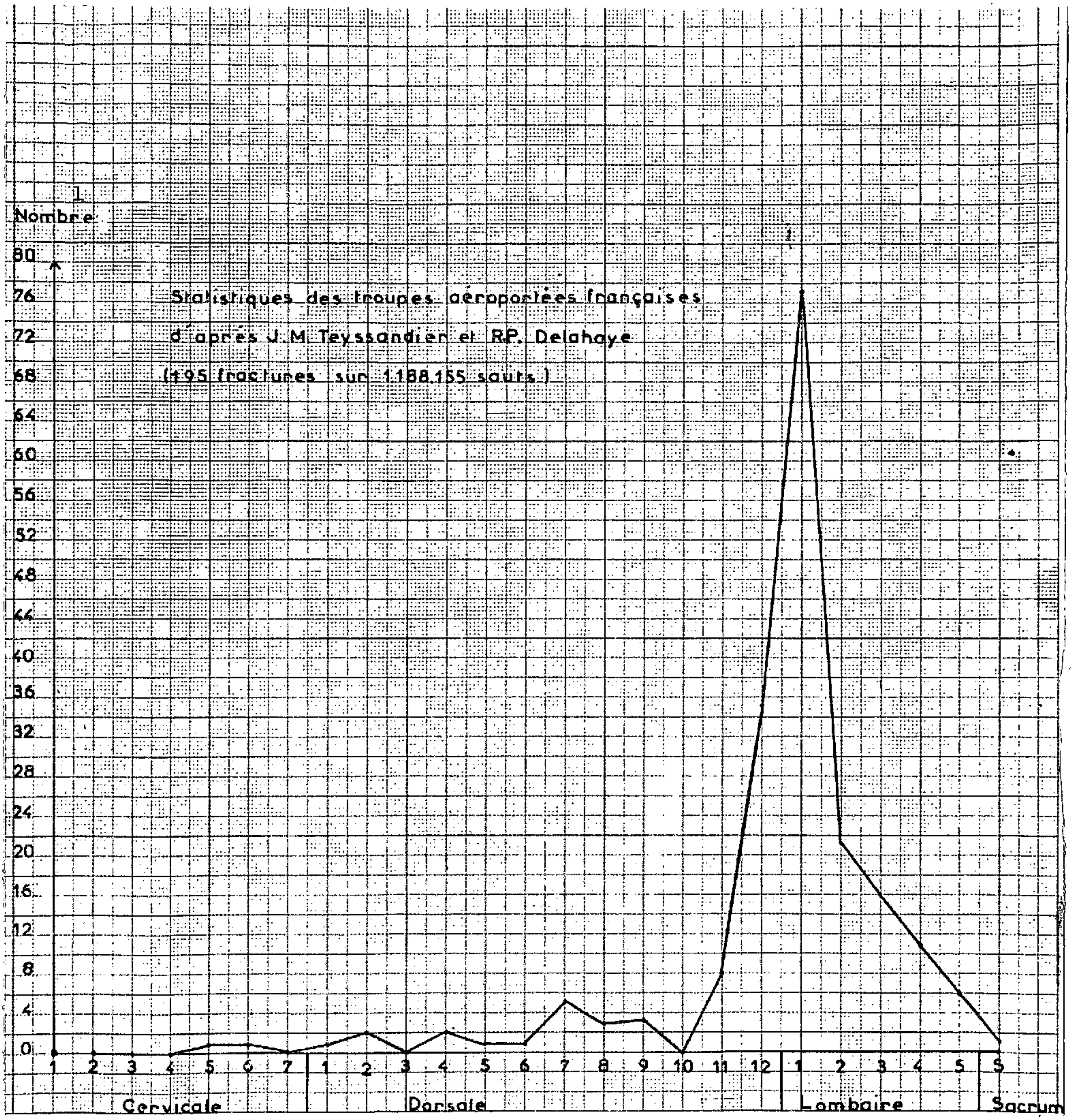

Fig. 2. Statistics on French airborne troops, after J.M. Teyssandier and R.P. Delahaye (195 fractures in 1,188,155 jumps).

Key: 1. Number

TABLE IV. /8

Army	Number of Pilots with Multiple Fractures	Number of Pilots with Fractures
U.S. Air Force	9	17
F.A.F.	7	20
G.A.F.	6	14
I.A.F.	3	15
R.A.F.	15	32

The distribution of multiple fractures (Table V) shows /9 that an infinite variety of combinations exists. It is difficult to confirm the presence of any preferred combinations related to the anatomical physiology of the spine. Nevertheless, there are frequent combinations of:

-- multiple dorsal injuries,

-- fractures in the area between D_{11} and L_2, which may be isolated from or associated with other sites.

It should be noted that spinal fractures may occur at different sites with the same type of seat, depending on the aircraft used and the operational use. (A curve drawn from the B.H. Kaplan report is very meaningful on this point.) (Fig. 3.).

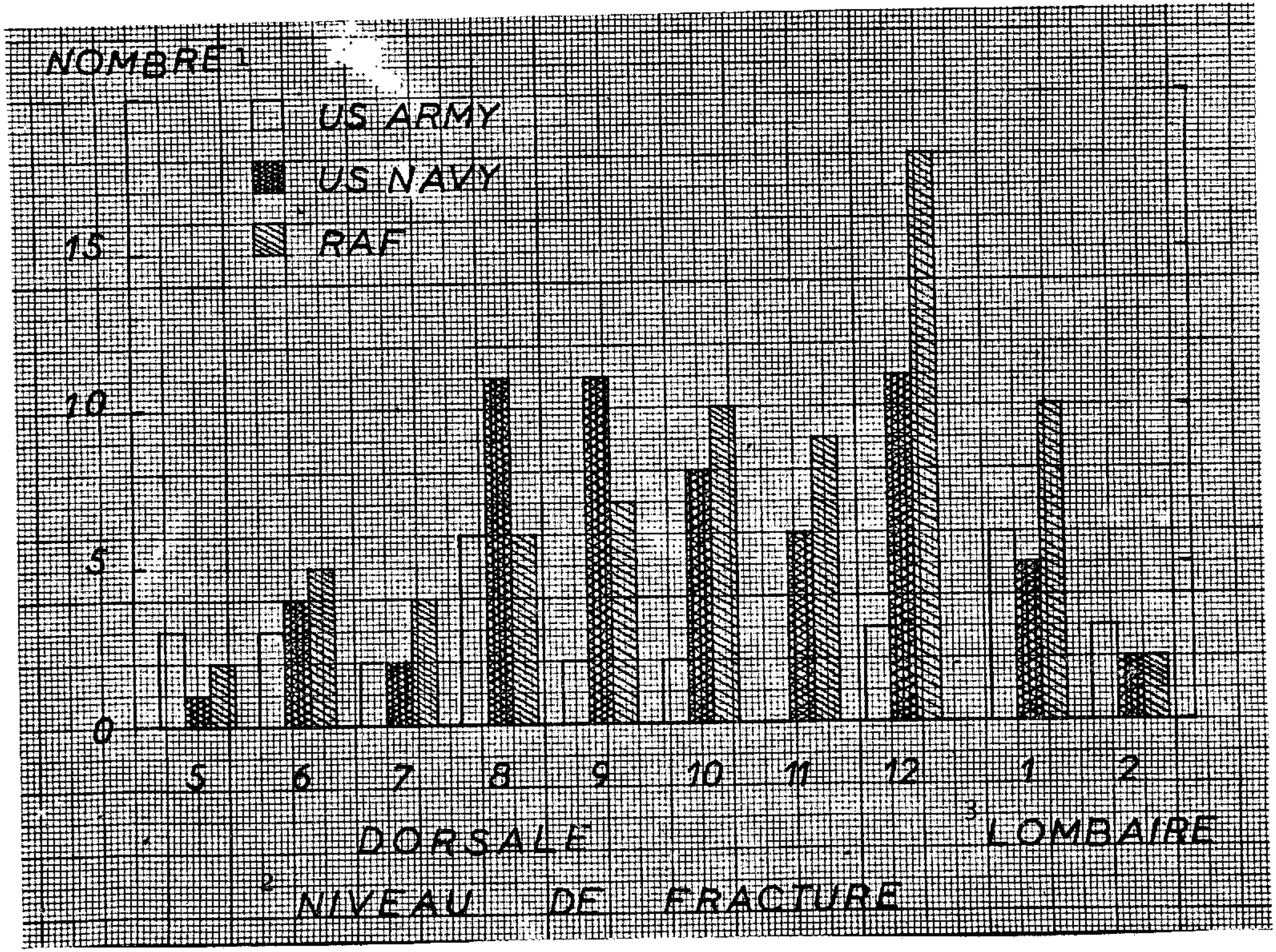

Fig. 3. Spinal fractures occurring with use of the same type of seat M.K.J-5 by different armed forces (U.S. Army, U.S. Navy and the RAF).

Key: 1. Number; 2. level of fracture; 3. lumbar

TABLE V.

	U.S.A.F	F.A.F.	G.A.F.	I.A.F.	R.A.F.
$C_4 - C_5 - C_6$			1		
$C_5 - C_6 - C_7$	1				
$C_5 - D_4 - D_5 - D_8 - D_9 - D_{10}$	-	-	-	-	1
$D_3 - D_4 - D_5 - D_7$	1	-	-	-	-
$D_4 - D_5$	-		1	-	-
$D_5 - D_6$	1		1	-	-
$D_5 - D_6 - D_7$	-	1	-	-	-
$D_5 - D_6 - D_{10}$	-	-	-	-	1
$D_6 - L_2$	-	1	-	-	-
$D_6 - D_9 - D_{10} - D_{11}$	-	-	-	-	1
$D_7 - D_8$	1	1	-	-	-
$D_7 - D_8 - D_9$	-	-	-	-	1
$D_7 - D_8 - D_{12} - L_1$	-	-	-	1	-
$D_7 - D_8 - D_{10} - D_{11} - D_{12}$	-	-	1	-	-
$D_8 - L_1$	-	1	-	-	-
$D_9 - D_{10} - D_{11}$	-	-	-	-	1
$D_9 - D_{12}$	-	-	-	-	1
$D_9 - D_{10} - D_{11} - D_{12}$	-	-	-	-	1
$D_{10} - D_{11} - L_1$	-	-	-	-	1
$D_{11} - D_{12}$	1	-	-	-	1
$D_{11} - D_{12} - L_1$	1	-	-	-	1

[Table continued on following page.]

Table V [continued]:

	USAF	FAF	GAF	IAF	RAF
$D_{11} - D_{12} - L_2$	-	-	-	-	1
$D_{11} - L_1 - L_2$	-	-	-	-	1
$D_{12} - L_1$	2	2	1	1	3
$D_{12} - L_1 - L_2$	-	1	-	-	-
$L_1 - L_2 - L_3 - L_4$	-	-	-	1	-
$L_1 - L_3$	-	-	1	-	-
$L_3 - L_4 - L_5$ - sacrum	1	-	-	-	-
TOTAL :	9	7	6	3	15

CHAPTER II. MECHANICS OF OCCURRENCE OF SPINAL FRACTURES /11

1. Anatomic Review
    1.1. Spine
    1.2. Intervertebral disk
        1.2.1. Mechanical characteristics
        1.2.2. Nutrition
        1.2.3. Aging

2. The mechanics of spinal fractures

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    3.2. Mechanics of occurrence of injuries upon departure of seat
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        3.2.4. Specific cases of ejection through a canopy
    3.3. Shock upon opening parachute
    3.4. Landing
        3.4.1. Characteristics of landing of ejected pilot
        3.4.2. Pathology of landing

In order to understand the pathogeny of these injuries, it /12 is necessary to review basic anatomic concepts on the anatomy of the spine and the mechanics of spinal fractures.

1. Anatomic Review

1.1. Spine

The spinal column as a whole forms a harmonious S-shaped line composed of a series of segments.

From top to bottom, four parts may be distinguished:

-- the cervical column, which is anteriorly convex;
-- the dorsal column, posteriorly convex;
-- the lumbar column, anteriorly convex;
-- the sacrococcygeal column, posteriorly convex.

Anatomically and physiologically, the column may be diagrammed in the form of two segments separated by the 12th dorsal vertebra: the cervicodorsal segment above and the lumbosacral segment below.

The modulation from one flexure to the next is gradual and virtually unnoticeable The vertebral type characteristic of each flexure is extremely distinct in the median position of each segment, but the transition effaces any special characteristics and the hinge vertebrae simultaneously possess characteristics of the supradjacent and subjacent flexures. Vertebrae of the farthest projecting points (D6, D12, L1) frequently have an anterior cuneiform configuration. The levels of transition vary from one subject to the next, resulting in several varieties of flexures.

The different segments consist of vertebrae which are articulated in two areas (Fig. 3).

1.2. The Intervertebral Disk (Fig. 4):

is formed of a gelatinous central nucleus, the nucleus pulposus, surrounded with concentric cylindrical layers of fibrocartilage, the annulus fibrosus. It is separated from the upper and lower vertebrae by cartilage plates covering the vertebral facet and participating in the physiology of the disk.

The nucleus pulposus is a spherical mass 1.5 to 2 mm in diameter at the lumbar stage, with a gelatinous consistency in young subjects. It may be assumed that the movement of the dense gelatinous part within the more fluid part contributes to the absorption of shock transmitted by the vertebral bodies.

1.2.1. Mechanical Characteristics (after J.G. Peyron)

In healthy condition, the intervertebral disk is a highly effective absorber and flexible transmitter of force.

The nucleus pulposus behaves as a hydrostatic medium, that is, it distributes the forces applied to it equally in all spatial directions. More or less compressible, but perhaps capable of viscous deformation, it translates the compression forces received from the two adjacent vertebrae into centrifugal force which distends the laminae of the annulus fibrosus, which due to its elasticity is particularly well suited to dissipate this type of force. Its resistance is considerable. Experimentally, the vertebral bodies will succumb to heavy pressure and will be fractured; however, this type of force causes no prolapse if the disks are healthy. The fact that it is composed of interlaced oblique fibers affords the annulus extreme resistance to forces exerted in a horizontal plane. On the other hand, this structure permits moderate lateral inflection (intervertebral angulation) (J.J. Galante). Thus a compromise is reached between spinal stability and flexibility.

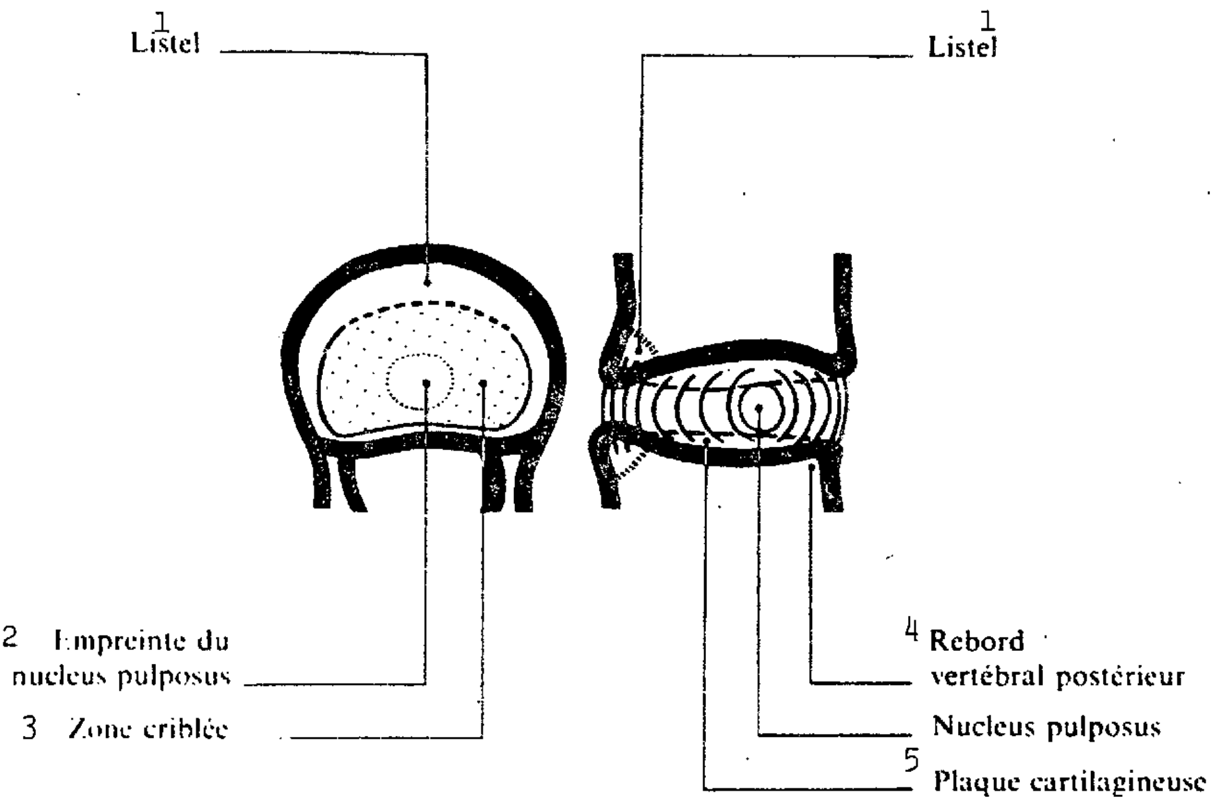

Fig. 4. The intervertebral disk (after Schmorl). /13

Key: 1. Fillet
2. Imprint of nucleus pulposus
3. Sieve-like area
4. Edge of posterior vertebra
5. Cartilage plate

The elasticity of the perirachidial ligaments is due to the fact that their collagenic fibers gradually become aligned in parallel as they are gradually put under stress. The anterior ligament is slightly more resistant than the posterior ligament. (T.K.F. Taylor and K. Little). /14

A study of the pressure levels within the disk has been performed on cadaver spines. The same study has been performed in vivo in man by introducing into the nucleus pulposus a needle with a semiconductor stress gauge at its tip. The intranuclear pressure is approximately 1.5 times that transmitted to the vertebral facet per surface unit. Sudden increases in stress do not seem to cause unrecordable oscillations. The disk serves as an excellent shock absorber.

The nucleus pulposus absorbs more than its share of vertical /15
pressure, while the annulus fibrosus receives only a part of this pressure. The force applied per surface unit would be 50% of that applied to the vertebral facet (in the case of equal surface area for the nucleus pulposus and the annulus fibrosus in horizontal cross section). The forces of centrifugal distension applied to the laminae of the annulus have been estimated at 3 to 5 times that transmitted by the vertebrae (per surface unit); however, a portion of this force is probably absorbed by the radial resistance of the cartilage plates.

In vivo, the posterior column (formed by the articular processes) transmits approximately 20% of the weight, leaving the rest to the somatodiscal anterior column.

These data are valid for an erect standing position. When an intervertebral articulation is given an inflection, the intranuclear pressures quickly increase by 0.7 kg/cm^2 for 5° angulation between two adjacent vertebrae. In vivo, normal day-to-day movements and positions produce appreciable excess pressure. The multiplication factor is on the order of 1.2 to 2.5 for the seated position, coughing, and normal bending. This reaches 2.5 to 3.5 in lifting a weight. Dorsal decubitus decreases the pressure by 50% (L. Nachemson and G. Elfstrom). A residual base pressure exists in the nucleus pulposus due to its characteristic turgescence, to the elasticity of the perivertebral ligaments and in vivo to the tonus of the perirachidial musculature.

Measurement of the lateral convexity of a disk under pressure reveals the very slight nature of its deformability: the lateral edge increases only 0.75 mm under 100 kg of pressure, with a 4 mm loss in height. In addition to bending movements and movements of the spine, the spinal column also undergoes torsion deformation, which always appears to be associated with the preceding types. If the vertical axis around which these torsion movements are performed passes through the center of the disk in the cervical and dorsal stages, it passes well to the back of the lumbar region at the level of the posterior axis. As a result, the lumbar disks are subjected to extremely heavy pulling forces (G.G. Gregensen and D.B. Lucas).

1.2.2. Nutrition /16

The adult disk, an avascular organ, is nourished by imbibition. The exchange is very active: simple substances such as sugar and urea diffuse easily through the disk, at half the rate at which they diffuse through water.

1.2.3. Aging

At a very early stage the disk begins to show signs of involution, and the first regressive changes are encountered prior to age 20. Between ages 20 and 30 dissolution of continuity appears between some laminae of the annulus. At age 40 the nucleus pulposus begins to undergo a fibrous involution, losing its gelatinous and turgescent appearance. Its separation from the annulus fibrosis becomes vague.

In reality, although these symptoms of disorganization may be detected very early in some disks, they are also very erratic.

The mechanical properties of the annular disk, extensibility, residual deformation, and energy dissipation capacity, decrease during childhood. Beginning with age 25 they stabilize, and healthy disks will undergo no further variations (J.J. Galânte). Physiological stresses seem to offer no serious threat to their healthy condition. Similarly, the extensibility of the anterior and posterior perirachidial ligaments decreases in appreciable fashion until adolescence, but subsequently there is virtually no further decrease (H. Tkaczuk).

The operation of these structures as a single unit is assured by:

-- the articular processes, which "bolt" the spinal column together;

-- the common anterior and posterior ligaments, forming an extremely strong continuous sheath. The opposition of the ligaments equilibrates the movements of the spinal column;

-- the intervertebral ligaments, which firmly connect the transverse and spinous processes. These restrain the motions of the articular processes; /17

-- the paravertebral muscular masses. These come into play in the physiology of spinal movements by providing action in opposition to passive movements. They are able to tolerate pressures greater than one ton.

The structure of the dorsolumbar vertebrae reveals their vulnerability.

The vertebral body consists of a thin layer of compact bone surrounded by a large mass of spongy bone. The trabecular lines of the spongy bone form three systems: a horizontal system, a vertical system, and most importantly an oblique system consisting of a superior oblique bundle and an inferior oblique bundle which are extended on the posterior arch.

In addition to the bundles already mentioned, the posterior arch includes a transverse bundle and a U-shaped bundle (Figs. 5 and 6).

Consequently the anterior and median parts of the vertebrae are virtually devoid of fibers and are predisposed to compression. On the other hand, the extremely tight intersection of the superior and inferior oblique bundles at the level of the insertion of the pediculus arcus vertebrae increases the solidity of this area. The ligament at the pedicular or posterior wall insertion has considerable influence on the seriousness of spinal injuries.

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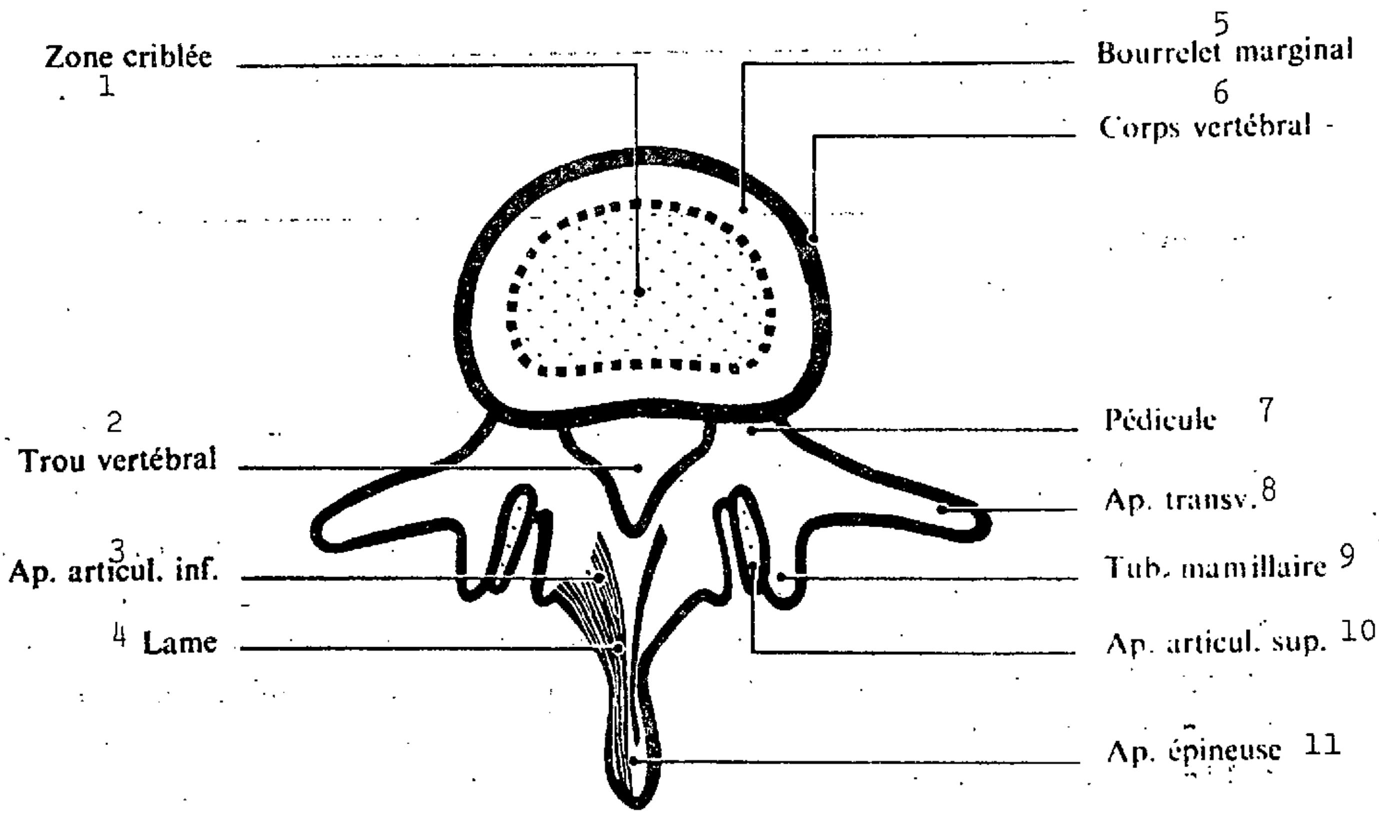

Fig. 5. Morphology of a dorsal or lumbar vertebra (after Paturet).

Key: 1. Centrum
2. Vertebral foramen
[Key continued on following page.]

Key to Fig. 5 (cont'd):

3. Inferior articular process
4. Lamina
5. Marginal cushion
6. Vertebral body
7. Pediculus
8. Transverse process
9. Mamillary tube
10. Superior articular process
11. Spinous process

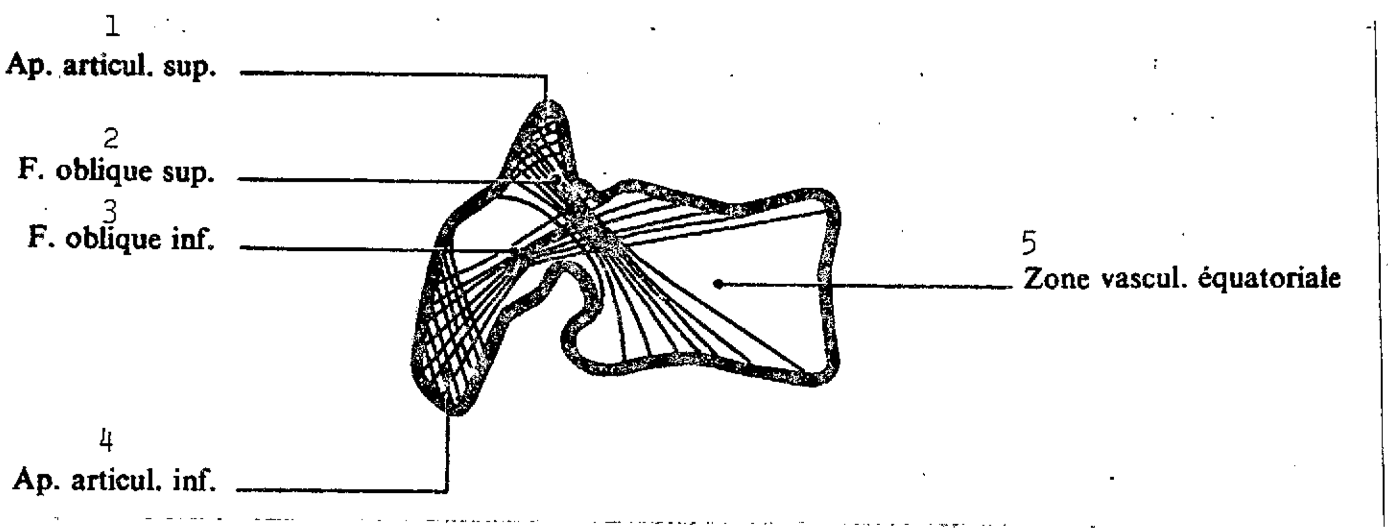

Fig. 6. Morphology and structure of a vertebra (after Paturet).

Key: 1. Superior articular process
2. Superior oblique fiber
3. Inferior oblique fiber
4. Inferior articular process
5. Equatorial vascular zone

2. The Mechanics of Spinal Fractures /19

Numerous pathogenic theories have been proposed on fractures of the dorsolumbar vertebrae.

According to Watson-Jones, there are three types of fractures depending on the direction of the shock (Fig. 7).

-- Anterior cuneiform fractures. Here vertical pressure is exerted on a column with a slight anterior flexion. The force is absorbed by the anterior part of the vertebrae, which are deformed in a wedge configuration. The vertebrae affected are injured solely on the anterior part of the vertebral body. Neither the posterior wall nor the disks and interspinal ligaments are affected.

Lateral flexion of the trunk has exactly the same effect, but in this case the vertebral compression is asymmetrical, being greater on the side toward which the trunk is bent. By definition these fractures are termed stable;

-- Comminuted fractures: The force, rather than being vertical, is applied in an oblique direction from top to bottom and from back to front. In response the spine enters hyperflexion. The angulation becomes so severe that the antero-inferior edge of the superior vertebra penetrates the upper surface of the subjacent vertebral body. The intervertebral disk is generally torn and the ligaments are frequently ruptured;

-- Fracture-dislocations: The traumatic thrust occurs perpendicular to the axis of the spinal column. The trunk is forced into hyperflexion while it is simultaneously drawn forward. The posterior wall is always broken, with severe damage to the ligaments. These fractures are extremely unstable and the prognosis is severe; not infrequently, there are injuries to the spinal cord.

The strength of the vertebrae has been studied in cadavers in numerous instances, but this type of examination is of limited practical applicability.

Rieunau has performed experiments on blocks of three dorsolumbar vertebrae still possessing their disks and ligaments.

Subjection of these vertebral units to pressure and monitoring the subsequent deformation by front, side and three-quarter view x-rays yielded the following results: /21

-- from 600 kg to 700 kg the vertebrae showed cracks and compression, and there was hemorrhagic sweating;

-- complete rupture occurred at pressures on the order of 850 kg.

In our opinion it is difficult to apply the results of these experiments to ejection, since they fail to take into account the most significant elements in spinal biodynamics:

-- the important damping role of the nucleus pulposus and the perirachidial muscular masses,

-- the direction of application, magnitude and time of application of the forces.

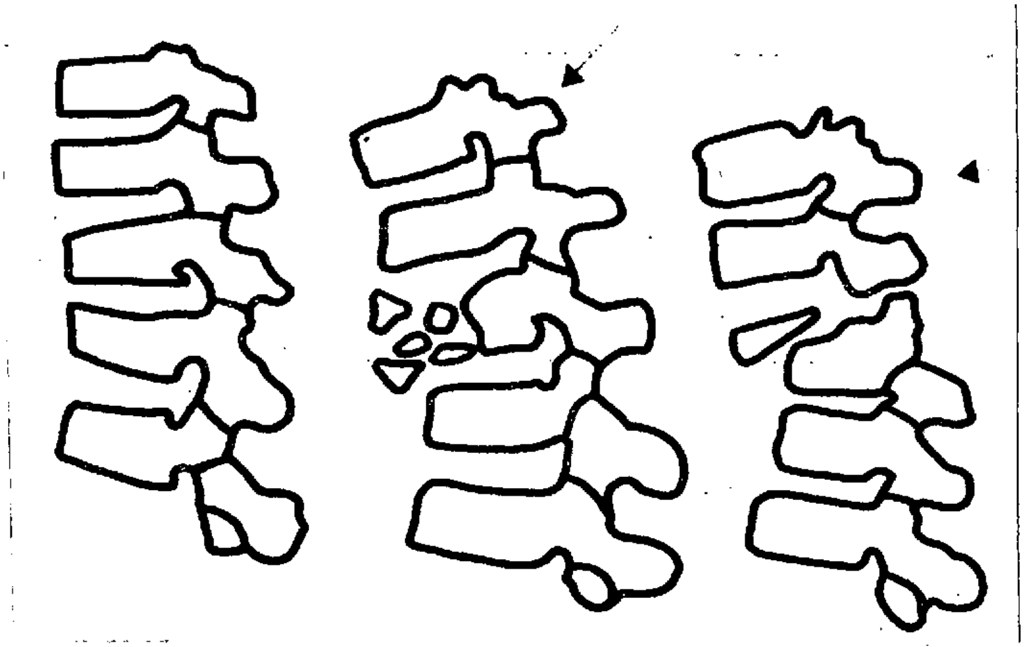 /20

Fig. 7. Mechanics of spinal fractures (after Watson-Jones).

3. Physiopathogenic Mechanism of Spinal Fractures During Ejection /21

3.1. General Remarks

Spinal fractures occur basically during two critical phases of the ejection process:

-- ejection of the seat,
-- landing.

The seat-pilot separation phase and the opening of the parachute will be discussed briefly since these procedures are not capable of producing injury except in cases of equipment malfunction.

3.2. Mechanics of Occurrence of Injuries During Seat Ejection

As they are ejected, all current ejectable seats produce acceleration compatible with the strength of the vertebral structures: accelerations of less than 20 g for 20 to 50/100 of a second, producing a jolt which in practice is less than authorized standards (250 g/sec).

Figure 8 shows acceleration curves for the MK 4 (Standard) and AM 6 (rocket) seats.

----- MK 4 standard seat

Max. acceleration = 20 g
Seat velocity = 80 ft/sec
Rate of change in
in acceleration = 240 g/sec

——— AM 6 rocket seat

Max. acceleration = 15 g
Seat velocity = 160 ft/sec
Rate of change in
acceleration = 200 g/sec

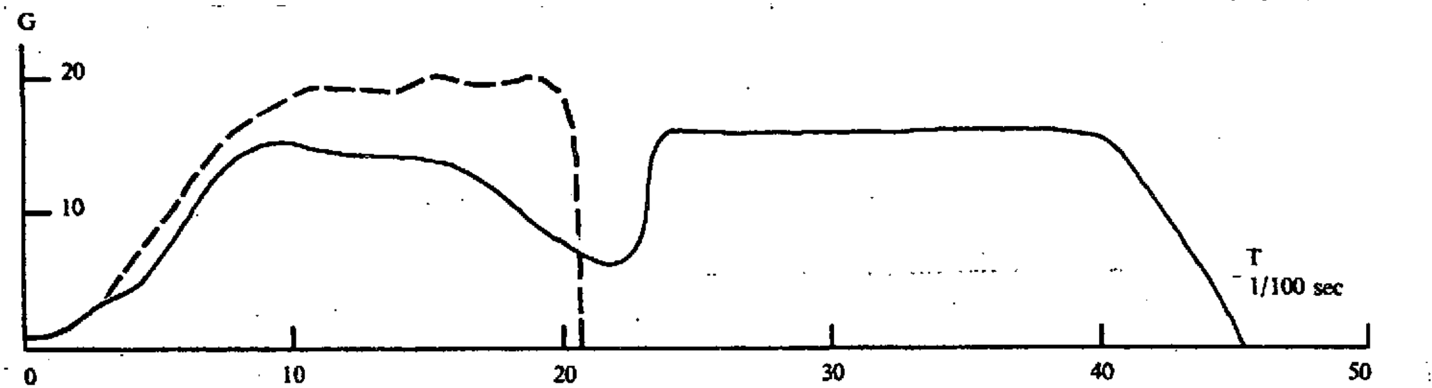

Fig. 8. Acceleration as a function of time. Ejections using two different seats (MK 4 Standard and AM 6 Rocket). (Measurement of acceleration at the level of the seat, the pelvis, the head and the vertebrae.) Weight ejected: seat + pilot = 172 kg.

The most important factor is the position of the pilot at the moment of ejection.

3.2.1. Role of Position of Pilot /22

Many investigators agree with Rotondo that the position of the body is the most important pathogenic factor in the mechanics of occurrence of spinal fractures.

Any abnormal position will weaken the spinal column and may produce injury, even at a rate of acceleration which would otherwise be tolerable.

A large number of factors affect the position of the pilot.

The attitude of the aircraft at the time of ejection is of importance. This modifies the pilot-seat relationship. Thus in ejections with the head in a low position the pelvis is forcibly separated from the seat, even if the safety straps are completely fastened. Similarly, when the aircraft is tilted to one side during ejection there is a lateral flexion of the trunk whose severity depends on the appropriateness of harness design.

If the harness is fastened too loosely there is excessive freedom of movement for the trunk, which bends considerably during ejection, resulting in major risk for the spine.

Forward flexion of the trunk is limited by the curtain and by the straps. When the low-positioned control system is used, Rotondo finds that flexion is more marked for ectomorphic subjects with a long thorax and shorter arms. Under these conditions, it is possible that the pilot will be unable to place his spine against the seatback completely and correctly during the extremely short period of time between triggering of the ejection procedure and the ejection itself.

According to the various papers consulted, the use of low control results in more spinal fractures than use of the curtain.

The fractures occur in the spinal flexures:

-- at the dorsolumbar hinge, /23

-- at the center of the D_6, D_7 and D_8 area, or still lower, at L_3; the vertebrae located in the middle of each flexure are the weakest points in the spine. On the other hand, when the pilot is seated in correct position, the natural spinal curvature is decreased; in normal seated position, the lumbar lordosis and the dorsal kyphosis of the spinal column are reduced. The column thus has a tendency to fall into a single alignment; this is the optimum position for tolerating ejection.

Radiographic studies using ejectable seats confirm the influence of several factors on dorsal spinal flexion.

-- The seat adjustment is of fundamental importance: The "low seat pan" position has a tendency to re-establish lumbar curvature and to accentuate the dorsal kyphosis. If in this case the legs are brought back under the seat, the lumbar lordosis is corrected but the dorsal kyphosis remains unchanged. There is thus an angulation in the D_4-D_5-D_6 area. On the other hand, when the seat is in normal position, folding the legs does not change the curvature of the spine. The height of the seat pan should thus be adjusted according to the physical type of the subject. This height should be proportional to the height of the canopy (GAF) and should be adequate so that the thighs remain in contact with the seat pan and the angle between the trunk and the thigh is 135°. From a statistical standpoint there are no valid relationships between physical type, weight and vertebral spinal injury (Kaplan, Barman), within the limits permitted by medical regulations on acceptance of aircrew personnel.

-- If the harness is too tight, especially if the anchoring points of the straps are in low positions, this may result in an increase in dorsal flexure depending on the physical type of the subject. Rapid fastening of the straps immediately prior to ejection may accentuate the flexion of the dorsal column and may cause fractures by compression (Auffret, Seris and R.P. Delahaye, 1963). Some modern ejectable seats are equipped with an automatic restraint system which exerts tension at the moment of ejection (power retraction unit). The attractiveness of such systems is statistically significant for MK 7 seats, where it decreases the risk of fracture (GAF). However, for MK 5 seats (U.S. Army), the advantages of this device seem to be more debatable.

-- The position of the head plays an important part. The head tends to bend forward, since in all circumstances the neck muscles are unable to remain erect, even with the use of a high control of the curtain type. This forced flexion accentuates the degree of flexion of the spine. Depending on the habitus of the subject (size, length of trunk, trunk-thigh ratio), the point of flexion occurs: /24

-- at the level of the dorsolumbar hinge D_{11}, D_{12}, L_1 in endomorphs and mesomorphs,

-- at the level of D_6, D_7 and D_8 in ectomorphs (where it may occur in conjunction with the above).

The elimination of flexion of the trunk at the moment of ejection is the sole means of eliminating the possiblity of spinal fracture (U.S. Army).

This flexion mechanism may be accompanied by rotation of the head. These two movements produce complex accelerations at the level of the dorsal spinal region. A helmet which is too heavy, poorly adapted or too wide in diameter may encourage rotation of the upper dorsal column when the head of the pilot is subjected to the relative wind. An identical mechanism is encountered during spin ejections, providing full justification for head restraint systems in specific uses (spin tests).

-- The angle between the axis of the spine and the axis of thrust (or enclosed angle) deserves special attention.

The ideal angle should be equal or very close to 0°. Wide angles favor the occurrence of injuries to the spinal column: even in correct ejection position, the column is not aligned with the axis of thrust. The consequences of a wide enclosed angle are the same as those of marked flexion of the trunk. The risk involved is that anterior cuneiform fractures may become comminuted fractures.

Most investigators find that all these considerations /25 justify the severity of the admission standards required for combat aircraft pilots. In particular, there is reason to reject candidates with marked accentuation of the natural dorsal kyphosis. X-rays of kyphotic subjects on ejectable seats show little change in the sagittal spinal curvature in the seated position, even when ejection procedures have been observed. The frequent presence of dorsal scoliosis in young adults has led us to question the possible influence of this postural problem on the risk to vertebrae during ejection. Due to the complexity of most ejection procedures, it is still too soon to determine the relative statistical significance of these postural abnormalities (scoliosis, accentuation of natural dorsal kyphosis).

3.2.2. Ejection in Abnormal Configurations

The altitude of the aircraft may be modified. In some cases ejection occurs while the aircraft is upside down or tilted. Loss of control at a high rotation speed during rolling is not infrequent. The acceleration may be linear, circular or angular. In these configurations, only the harness will keep the pilot in his seat. There is a risk that the back will not be in contact with the seatback, and that the body of the pilot will not always be in contact with the seat cushion. Consequently the dynamics of ejection will be modified.

In a tight turn, the acceleration produced by the maneuver will be added to the acceleration of the seat. In a low-speed spin in modern aircraft, the acceleration "Ax" developed by the rotation of the aircraft will hurl the pilot forward in his harness, and the anchoring points of this harness being in a low position, the spine will be in forced flexion This change in the spinal posture favors the occurrence of fractures at the moment when the seat is ejected.

These considerations indicate that the position of the pilot should be as follows: /26

-- head erect, back and buttocks uniformly in contact with seat;

-- straps of harness adequately tightened, but not excessively;

-- the feet may remain on the rudder bar if the seat possesses leg clamps. If it does not, it is absolutely imperative to place the feet in the stirrups;

-- the position of the seat pan should not be changed at the time of ejection;

-- individual equipment, especially the helmet, should be chosen with the greatest care. Helmets which are too large have a tendency to accentuate the curvature of the dorsal column. In addition, they are more easily torn off.

3.2.3. Transmission of Acceleration to the Seat-Pilot Unit. Importance of Cushion

The following example is highly representative and indicates the importance of a factor as simple as the seat cushion.

During overseas flight, a pilot found it necessary to abandon his aircraft due to mechanical failure. For this type of mission, the rigid seat padding was replaced by a more flexible assembly including a folded inflatable liferaft on the seat. In addition, for reasons of personal comfort the pilot had added a thick synthetic foam cushion.

The aircraft was abandoned under ideal conditions: the pilot placed the aircraft in horizontal flight at an altitude of 2000 m and reduced its speed to 200 knots; he fastened his harness, minutely inspected its position and even took the time to consult his ejection manual.

At the moment of ejection, he felt a sharp shock and shortly afterward became conscious of violent back pain.

The arrival on the ground was also exceptional; there was no direct contact with the ground, since the parachute was caught in the branches of a tree.

X-ray examination revealed a fracture of the eighth dorsal vertebra.

The nature of the landing did not play any part in this particular case. The ideal conditions of the ejection should not have resulted in injury. The vertebral fracture was thus due to the modified cushion: its use distorted the transmission of acceleration to the pilot; this acceleration, generally within the limits of human tolerance, exceeded resistance thresholds. /27

-- Experimental Study

Experimental results confirm these findings. Investigators have recorded accelerations during several series of experiments with dummies. Accelerometers were affixed to the seats and to the dummies at various levels (hips, shoulders, head). It was possible to compare several types of cushions.

The results are convincing:

-- the difference between the acceleration curves of the seat and of the pelvis of the dummy varies as a function of the cushion used;

-- the hardest cushions give the best results: in these cases the two recorded curves are almost identical;

-- the rate of acceleration at the level of the hip is generally higher than the rate of acceleration of the seat;

-- in any given experiment the rate of acceleration is higher closer to the head.

-- Mechanical Theory on the Seat-Pilot Unit

The simplified mechanical equivalent of the ejected unit may be represented by two distinct masses, connected to each other by a spring-damper system corresponding to the elasticity and damping capability of the cushion.

If the spring is extremely rigid (or the damper is infinite), the rate of acceleration recorded for the pilot is practically identical to that for the seat. Any movement of the seat results in a movement of the dummy. /28

Inversely, if the spring is not very rigid, it is initially compressed, and the acceleration is transmitted to the subject with a phase difference. This delay corresponds to the relative displacement of the seat in relation to the subject. The movement is transmitted only when the spring has been compressed beyond its equilibrium position. In a second phase, the spring begins to oscillate around its equilibrium position. The energy stored up by the spring during the first phase is added to that of the pyrotechnical cartridge. A temporary acceleration peak for the dummy is recorded. In addition, this higher rate of acceleration is reached in a shorter period of time: the rate of increase in acceleration is increased.

In reality this formula is oversimplified. The dynamics of the spinal column itself modify the transmission of acceleration.

The classic diagram of Dieckman (1957) cited by R.R. Coermann (1962) explains the relationship between the initial excitation (acceleration of seat) and its modifications in the human body (Fig. 9). The human body is an assembly of suspended masses. Systems of springs and dampers (ligaments, muscles, intervertebral disks, etc.) link the principal body masses (head, chest and arms, pelvis and legs).

The concept of frequency of resonance is of prime importance. This factor dominates the physiological effects of vibration and acceleration on the human body. These effects depend on the frequency imposed and the frequency characteristic of each body segment. There is resonance, that is, high displacement amplitudes, when the frequency of forced oscillations is equal to the characteristic frequency of the system (Fig. 10).

In order to avoid overacceleration points, it is necessary to filter the frequency to a maximum of 5 Hz, the principal resonance frequency of the spinal column, pelvis and legs. Elastic cushions have an unfortunate tendency to amplify the frequency by 5 Hz (in a period of 0.20 sec), the length of the /30
propellant phase for many types of seats.

In conclusion, the seat cushions should be extremely rigid. Comfort is improved by increasing the support surface area (contouring the contact surface). The use of flexible cushions remains possible with the express condition that they be completely compressed by the weight of the pilot alone. With these reservations, no changes are introduced into the oscillatory seat-pilot system.

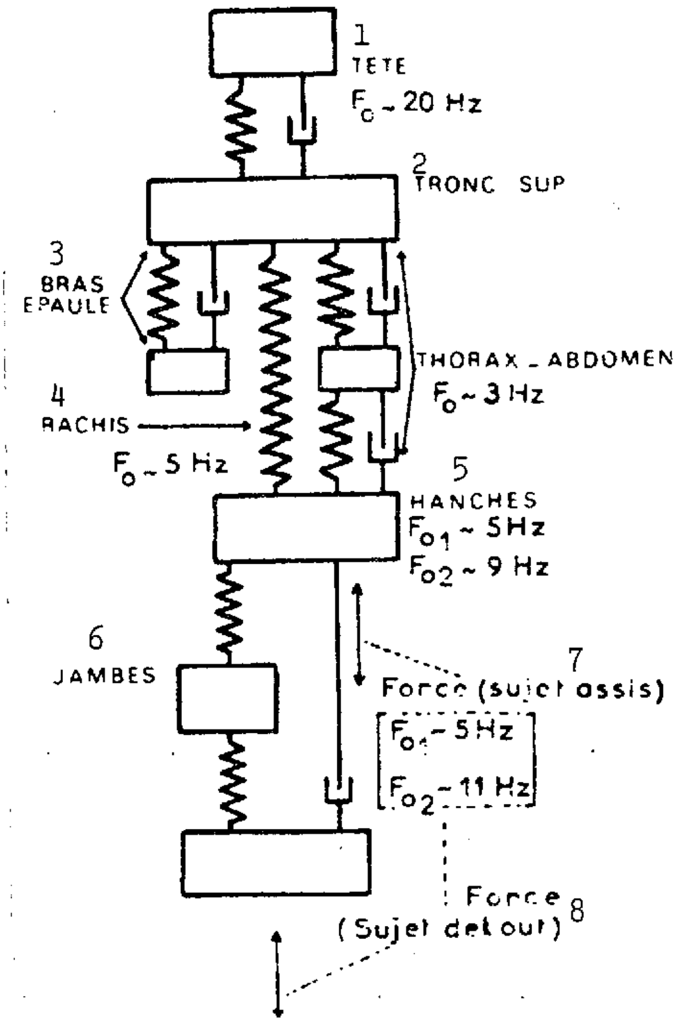

Fig. 9. Resonance of a human body subjected to 5 and 11 Hz vibrations (FO = natural frequency) (after Coermann).

Key: 1. Head
2. Upper trunk
3. Arm, shoulder
4. Spine
5. Hips
6. Legs
7. Force (seated subject)
8. Force (standing subject)

This study shows that only officially approved cushions should be used on seats.

At the present time these problems with regard to cushion type seem to be well under control, since survival-rescue kits are contained in extremely rigid envelopes, sometimes constructed of plastic.

Finally, it appears that the limits defined for rates of acceleration + + Gz (25 g for a period of 0.10 sec; jolt 250 g/sec) represent the maximum values for the pilot and not for the seat.

3.2.4. Specific Case of Ejection Through a Canopy

Under certain circumstances the ejection will occur through a canopy.

The force necessary to burst the canopy is extremely small in relation to the force of ejection. The final velocity of the ejected unit undergoes little change: a decrease of 0.30 to 0.60 m/sec.

On the other hand, the acceleration curve is disturbed. An acceleration peak is introduced which is linked to the bursting of the canopy.

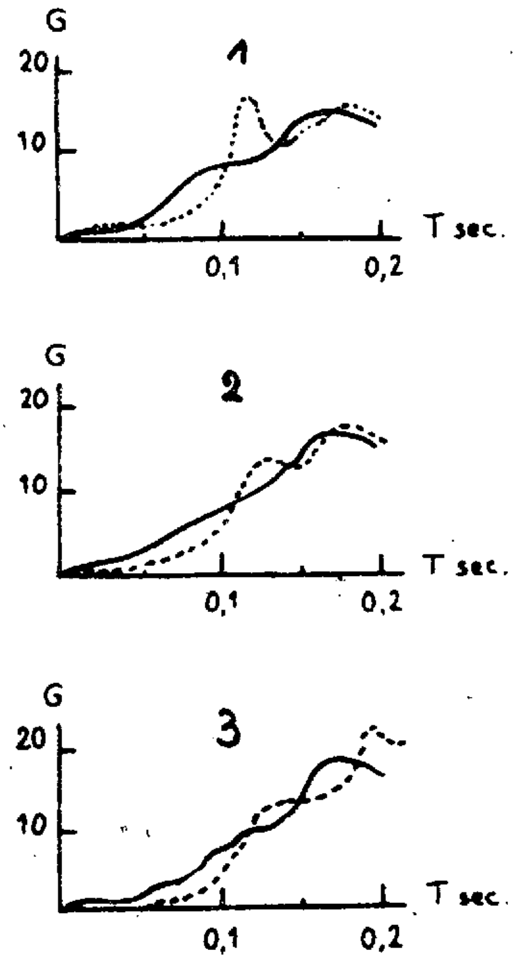

Fig. 10. Acceleration curves with several types of cushions (after Latham).

1. Parachute, inflatable life-raft and water-filled cushion.
2. Parachute and thin felt cushion.
3. Parachute and thick felt cushion.

—— Rate of acceleration of seat.

--- Rate of acceleration of hip of subject.

The pressure of the gun is momentarily counterbalanced by the resistance of the canopy. Pressure accumulates in the tubes of the gun. When the canopy is burst, the accumulated pressure is released in the form of a sharp, but very brief shock.

Experimental recordings /31
show that this shock is sometimes as high as 1000 g/sec, but its length never exceeds a few thousandths of a second. Consequently a 40 g peak at the level of the seat produces only 21 g for the pelvis and 38 g for the head. Compression of the vertebrae is moderate: 2.25 KN, that is 225 Kg (Fig. 11).

The acceleration is transmitted from the pelvis to the head in 3/100 sec. If the length of the acceleration is shorter than this value, the head will undergo acceleration while the vertebral compression will be smaller.

Inversely, for greater /32
periods of acceleration, all the damping systems are restrained and the vertebrae undergo compression $F = m\gamma$.

The work of J.P. Stapp has shown that any acceleration less than 0.01 sec and 80 g entrains no risk for a normal spinal column in satisfactory position.

The acceleration point of ejections through a canopy limits the thickness of conventional plexiglass canopies to 9 m [sic]. In order to decrease this acceleration peak, current research is attempting to produce pyrotechnical systems

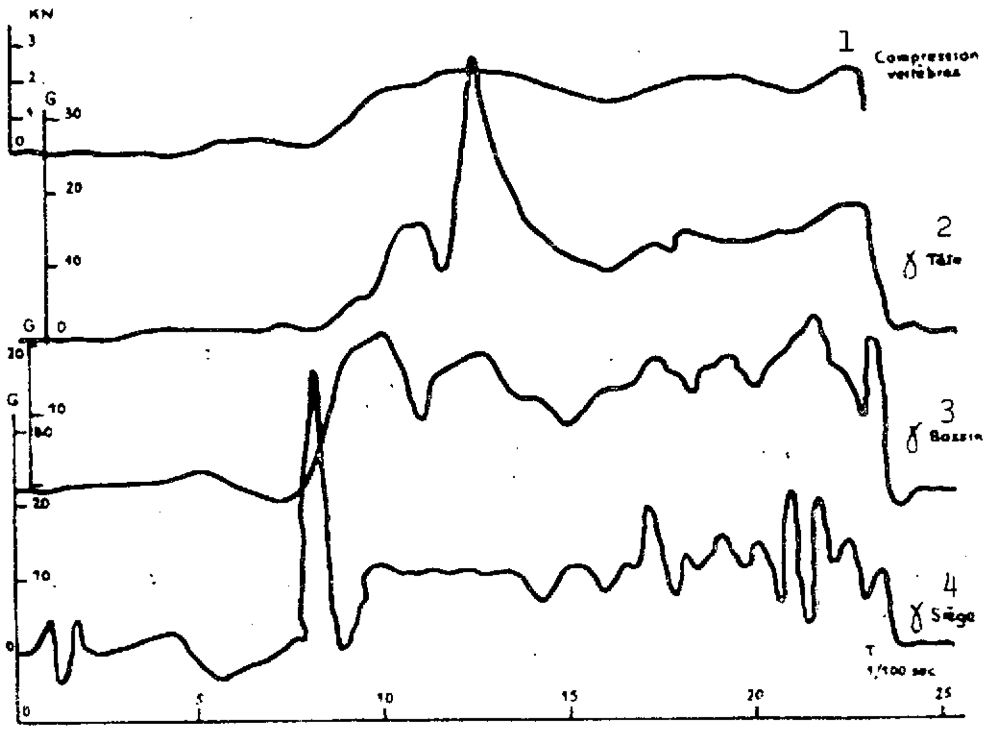

Fig. 11. Ejection through a canopy using an MK 4 seat. Recording of rates of acceleration.

Key: 1. Compression of vertebrae
2. Head
3. Pelvis
4. Seat

designed to weaken the canopy. These devices create cracks in the canopy. Their powder charge should not be very high, since the shock wave occurs very close to the pilot and may cause injury.

Worldwide, nearly 500 ejections through a canopy have been performed. The percentage of injury is not much higher than that for conventional ejection procedures; nevertheless this system is still more dangerous, especially due to the risk of injury by fragments of plexiglass.

All current seats are equipped with "canopy knives" and permit such ejection procedures. This system is only a safety device designed to gain precious fractions of a second.

This type of safety mechanism is imperative for vertical takeoff aircraft. The absence of relative wind in phases of stationary flight does not permit correct jettisoning of the canopy.

3.3. Shock upon Opening Parachute

The unfolding time of a parachute is a function of the filling of its canopy. The distance required for complete opening varies with the size of the parachute, but is independent of the speed of movement.

It has been experimentally determined that a parachute must travel a distance 6 to 8 times its diameter before inflating. Inversely, the filling time is related to the drop rate. Shorter filling times correspond to higher drop rates.

Drop rates at higher altitudes are much greater than those /33
close to the ground. At 20,000 m the drop rate may be as high as 200 m/sec (400 knots), while close to the ground it varies between 45 and 55 m/sec (100 knots) (Fig. 12).

At high altitudes deceleration is fast and sharp due to the high drop rate. The shock occurring when the parachute is opened is violent (Figs. 12 and 13).

At 13,000 m, the time required for slowing down is one eighth that required at 2500 m.

The rate of deceleration is sometimes as high as 30 to 40 g.

K.E. Plecher and J.E. Neely (1960) have reported a case of death occurring due to atlantooccipital separation and injury to the spinal cord when the parachute was opened at an extremely high altitude.

Currently injury occurs only in cases of failure of the mechanisms designed to prevent opening of the parachute at excessively high altitudes or speeds.

None of the documents received noted vertebral injuries due to the shock incurred upon opening the parachute.

3.4. Landing

3.4.1. Characteristics of Landing of the Ejected Pilot

During the last 500 m prior to reaching the ground or the sea, the pilot should jettison a kit which most importantly contains a self-inflating liferaft. This raft remains connected to the pilot by a strap 5 m long. In the most modern evacuation systems, this assembly is sufficiently independent from the pilot so that he is not forced to be occupied with this maneuver at the last minute. This improvement will

certainly decrease the number of vertebral fractures of ejected pilots, since all statistics manifestly show a higher frequency of vertebral compression for pilots who have neglected to jettison this package. This has been explained by the fact that the survival kit represents an average of 8 to /35
10 kg additional weight which must be added to the weight of the pilot upon impact with the ground.

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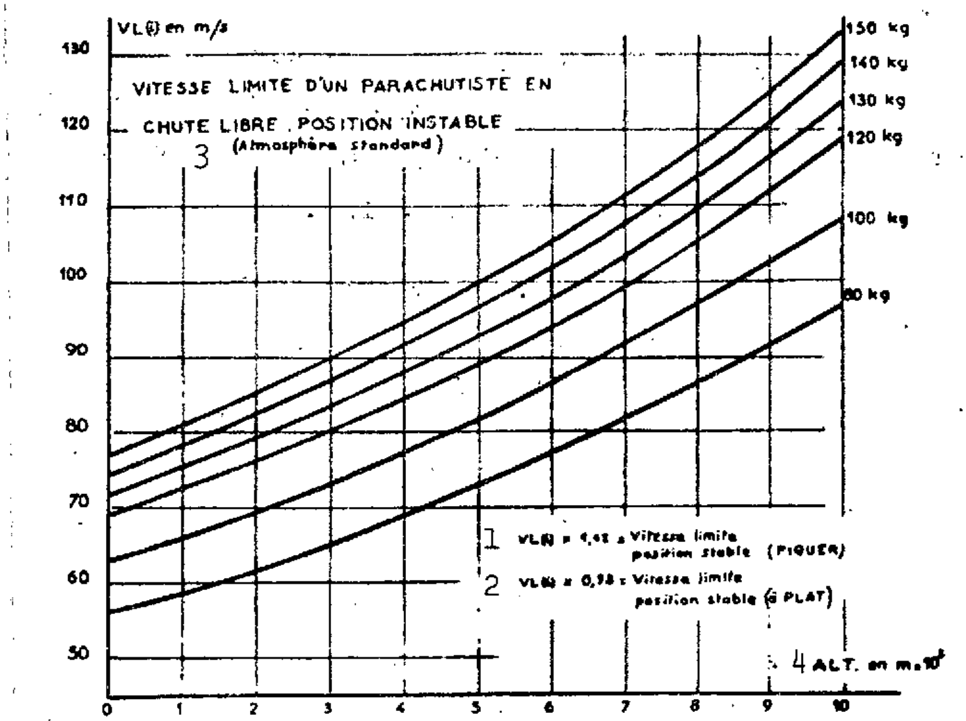

Fig. 12. Limit rate of descent of a parachutist in free fall as a function of his weight and position.

Key: 1. Limit rate of descent, stable position (dive)
2. Limit rate of descent, stable position (flat)
3. Standard atmosphere
4. Altitude in m

The pilot reaches the ground under special conditions dif- /35
ferent from those of the professional parachutist. Aircrew personnel will have had little training in parachute practice. Student pilots will sometimes make jumps prior to certification so as to familiarize themselves with parachute landing conditions. However, all countries do not make use of this type of training, whose value is moreover debatable, since it presents the risk of loss of costly personnel. Furthermore, there is every chance that ejection will occur a long time after this training phase.

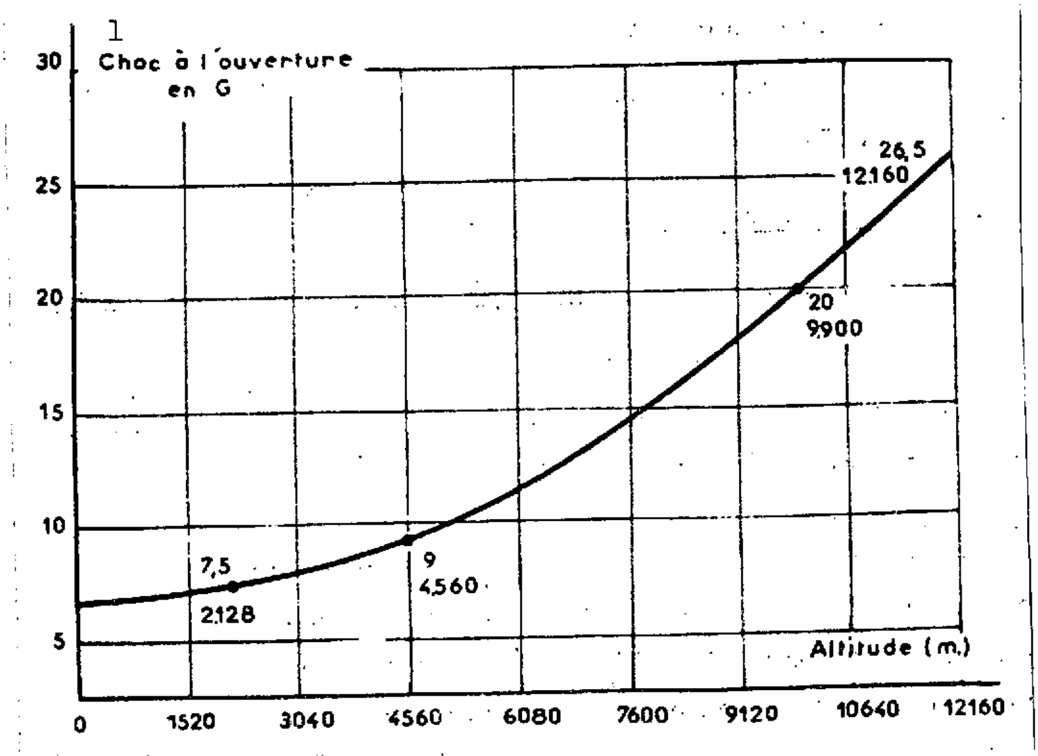

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Fig. 13. Degree of shock upon opening of parachute as a function of altitude (28 foot canopy).

Key: 1. Shock upon opening in g

The ejected pilot chooses neither the moment of ejection nor the terrain. Not infrequently the procedure must be carried out at night, under strong winds, on uneven terrain, over water, etc. /35

The canopy area of the parachute used is small (in most cases 40 m^2 rather than the 60 m^2 canopy used by paratroopers). The speed upon reaching the ground is therefore greater than that of a paratrooper.

Psychological factors must also be taken into account. Most often the pilot will be particularly relaxed in the parachute, since he will have just abandoned an aircraft about to crash and has thus assured his own survival.

There is a greater chance that his arrival on the ground, with muscles relaxed and in poor position, will be traumatic.

3.4.2. Pathology of Landing

Despite the restrictions set forth in the preceding paragraph, this pathology is related to the traumatology of the parachutist. The percentage of injuries attributable to landing is extremely high. R.H. Shannon estimates it as between 30 and 40%, depending on the ejection conditions. In medical investigations after ejection, moreover, it is frequently difficult to determine the moment at which the spinal fracture occurred (departure of seat, arrival on the ground).

A twofold mechanism operates upon impact with the ground. /36
There is simultaneously vertical pressure from bottom to top and hyperflexion of the dorsolumbar column.

The types of fractures observed vary: there may or may not be injury to the disks or ligaments, but the fractures are almost always anterior cuneiform or comminuted. Serious fractures with rupture of the posterior wall are rare.

Localization of these fractures in the D12-L3 segment with a sharp predominance at L1 may be explained by the position of the "hinge point." In forward flexion of the spine, the cervical flexure is reversed, the dorsal kyphosis is accentuated, and the lumbar lordosis is nullified, and then is reversed in forced flexion. Despite the inversion of its flexure, the lumbar column remains virtually vertical during these changes. One point remains fixed: this is the hinge point at which maximum flexion occurs. This level contains the breaking point, which is located at D12-L1 (Fig. 14).

A second argument in favor of this preferential site is furnished by M.J. Teyssandier and R.P. Delahaye in an x-ray study of parachutists in landing position. It was possible to use only x-rays taken in profile, since the opacity of the equipment to x-rays prevented the reading of front-view x-rays. The results are extremely interesting (Fig. 15).

The landing shock may be represented by a vector:

-- directed from bottom to top,

-- originating on the ground,

-- whose value varies with the square of the horizontal speed of the wind for a single parachutist.

This vector is located in a plane which passes through the ankles and hips, takes in vertebral bodies D12 to L3, and passes through the posterior wall of the spine at the level of the dorsolumbar hinge.

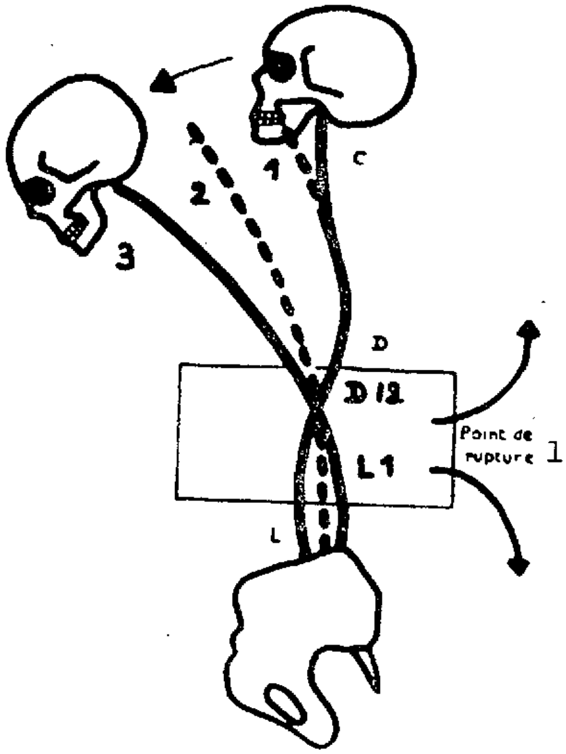


Fig. 14. Straightening of the lumbar flexure in forced forward flexion of the spine. Determination of the breaking point or hinge point (after E. Forgue).

Key: 1. Breaking point

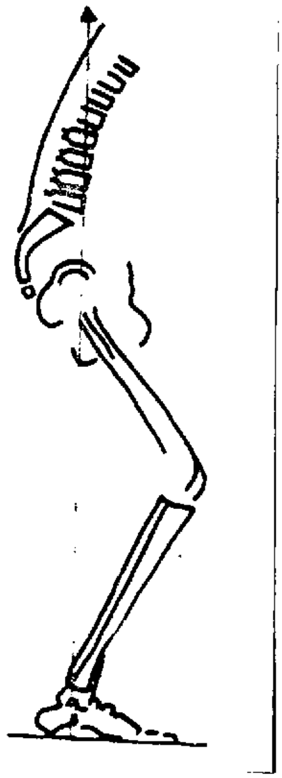


Fig. 15. Tracing of an x-ray of a subject in landing position. The arrow represents the direction of force on impact.

CHAPTER III. CLINICAL AND RADIOLOGICAL STUDY OF SPINAL FRACTURES /38

1. Clinical study
    1.1. Asymptomatic fractures
    1.2. Fractures with clinical manifestations

2. Radiology
    2.1. Technique
    2.2. Radiological appearance of spinal fractures
        2.2.1. Number and site of fractures
        2.2.2. Determination of stability and instability characteristics
        2.2.3. Fractures with intact posterior wall
            * Body shape
            * Appearance of angles and facet outlines
            * Density and structure of bony area
            * Injuries of the posterior arch
            * Displacements and postural disturbances
            * Related injuries
            * Concurrent injuries
        2.2.4. Fractures with injury of the posterior wall
            * Body shape
            * Outlines
            * Density and structure of bony area
            * Injury to the posterior arch
            * Displacements and postural disturbances
            * Related injuries
            * Concurrent injuries
        2.2.5. Isolated fractures of the posterior arch /39
            * Fractures of the processes
            * Fractures of the articular processes
        2.2.6. Special clinical forms
            * Fracture-dislocations
            * Fractures of the anterior body
            * Dislocations and subdislocations of the cervical column

3. Differential diagnosis
    3.1. Morphological variants
        -- Vertebra with cuneiform tendency
        -- Lack of fusion of the vertebral bodies
        -- Anterior retromarginal hernia
    3.2. Congenital abnormalities

1. Clinical Study /40

Several reporting organizations (HAF, IAF, FAF) note that there are no specific rules for clinical and radiological examination of combat aircraft pilots with spinal fractures. The examination performed is identical to that used for other types of injuries (highway accidents, athletic and occupational accidents). To the editors it appeared necessary to retain the basic rules set by the classical teaching of medical schools and universities in various countries, while recommending a few procedural variations.

It should be recalled that the USAF stipulates the procedure to be followed in the Air Force Manual, A.F.M. manual 127-2. Other air forces have not stipulated the steps to be followed but do require a given number of examinations (x-ray examinations, for example).

Two types will therefore be distinguished, depending on the absence or presence of clinical symptoms.

1.1. Asymptomatic Fractures

Occurring in 15 to 20% of the cases, these show no clinical manifestations. There is no pain or discomfort. Static and dynamic clinical tests are completely negative.

1.2. Fractures with Clinical Manifestations

These represent the majority of the fractures observed. Pain is the basic clinical manifestation in most cases. Usually localized in the dorsal or lumbar segment, and more rarely in the cervical region, this pain may assume two principal aspects. Sometimes violent, it appears at the time the trauma is incurred or immediately afterwards. This type of pain, intermittent or permanent and sometimes accompanied by seizures, results in severe functional impairment. In other cases, it may be so subdued that it initially remains unnoticed, but its intensity increases and it becomes apparent a few hours after ejection.

Clinical examination may exacerbate this pain. Palpation /41 and percussion sometimes pinpoint the site of the vertebral injury. The pain produced by palpation of the spinous processes is sometimes accompanied by a more or less strong contraction of the paravertebral musculature, accompained by limitation of active or passive movements of flexion, extension or rotation of the trunk.

Neurologic examination generally does not reveal nerve damage. However, cauda equina syndrome and paraplegia of rapid onset have been observed.

2. Radiology

The use of x-ray examination differs from country to country. Some armed forces such as the FAF, HAF, GAF, IAF and RAF consider spinal x-rays indispensable. Requirement of x-rays may be noted in the documents furnished by the GAF, IAF, FAF, RAF and HAF. In many cases the justification for systematic x-rays after ejection lies primarily in the fact that 15 to 20% of spinal fractures are not accompanied by clinical manifestations. In civilian medical practice there have been many instances of diagnostic failure in highway accident cases due to the fact that no reliable method capable of confirming the existence of a spinal fracture was used.

In the USAF the use of x-rays is recommended but not required. The same is true of the U.S. Army. It is the responsibility of the flight surgeon to decide whether the pilot should undergo an x-ray examination of the spinal column.

2.1. Technique

This is no different from the technique used for any spinal trauma. It seems important to recall a few basic concepts:

-- The entire spine should be x-rayed in both front and side views. Depending on the condition of the subject, the examination is performed standing or in decubitus;

-- The slightest abnormality should prompt localized x-rays in front and side views. The x-rays are taken from the concave side of each segment; /42

-- Right and left three-quarter views permit an analysis of the posterior arches.

Tomographs are extremely useful in most cases. They are frequently used by the FAF, GAF, IAF and RAF. Some organizations find that the data collected permit a finer and more minute analysis of the injuries observed. This does not seem to be the case with the USAF. The reporting officer has indicated that tomographs have not been performed for USAF pilots with fractures. In the U.S. Army tomography is apparently used for sites suspected to be the cause of the clinical symptomatology.

In general, tomographs are very frequently requested by orthopedic surgeons in Europe. Some medical schools are even of the opinion that this practice should be systematic.

Radiodynamic tests, if permitted by the condition of the pilot, make it possible to evaluate the intervertebral space and the ligament connections. The usual motions are inclination in right and left lateral flexion, flexion and extension. Dynamic study of the spine will sometimes reveal a pinching or a discal chasma, an enlargement of the space between the spinous processes (FAF, IAF).

POSITION OF VARIOUS ARMED FORCES ON THE USE OF X-RAY EXAMINATION. /43

Organization	Required Radiological Examination
USAF	No,but recommended if there are clinical symptoms.
U.S. Army	No, but recommended if there are clinical symptoms
FAF	Yes
GAF	Yes
HAF	Yes
IAF	Yes (entire spine)
RAF	Yes (entire spine)

[illegible] USE OF TOMOGRAPHY

Organization	Use of Tomography
USAF	Extremely rare
U.S. Army	Rare (as a function of clinical data)
FAF	Very frequent
GAF	Rare, but of prime importance when used
HAF	Rare
IAF	Very frequent
RAF	Fairly frequent

2.2. Radiological Appearance of Spinal Fractures

2.2.1. Number and Site of Fractures (Fig. 1)

X-rays and, if they are used, tomographs will show the number of injured vertebrae and their location. A study of 210 spinal fractures of ejected pilots from the various armed forces responding to the questionnaire from the Working Group shows that the following vertebrae are injured, in order of decreasing frequency:

-- the dorsolumbar hinge (D12-L1),
-- the dorsal column (beginning with D5, with a peak at D12),
-- cervical and lumbar sites are much less frequent.

The frequent presence of multiple spinal fractures justifies the systematic performance of x-rays of the entire spine.

2.2.2. Determination of Stability and Instability Characteristics

Determination of these characteristics must be of prime importance in any x-ray examination, since it provides the basis for evaluating the stability or instability of the injury. There is a high risk of secondary displacement during the days following reduction and immobilization. Nerve injuries may appear.

The stability and instability characteristics depend on three principal factors:

-- the comminuted nature of the fracture, which prolongs the healing time and increases the risk of any attempt at reduction;

-- shattering of the intervertebral disk;

-- rupture of the interspinous ligament, which never spontaneously detaches from the bone.

Nicoll and Holdsworth thus distinguish two large categories of fractures:

-- stable fractures without any risk of secondary displacement, consisting of:

* anterior compression,
* lateral compression,
* fractures of the posterior arch above L4.

-- unstable fractures, susceptible to secondary exacerbation by creating nerve injuries, and which are difficult to hold in a satisfactory reduction position. These include:

* fracture-dislocations by rupture of the interspinous ligament: marked anterior compression and comminuted fractures;
* fracture-dislocations;
* fractures of the posterior arch of L4 and L5.

A number of investigators justly remark that in some cases it is difficult to determine whether the fracture is stable or unstable. It is not possible to make a definite classification.

Many orthopedists join Rieunau in relating the concept of stability to the intactness of the "posterior wall," and others to that of the "resistance wall" consisting of the posterior part of the vertebral body on which are inserted the two pediculi, an area with extremely solid bone structure, together with its ligament covering. Spinal fractures may therefore be divided into two groups:

-- with injury to the posterior wall,
-- without injury to the posterior wall.

This classification is extremely valuable in determining treatment methods, since radically different therapies are indicated for these two groups.

Spinal fractures in which the posterior wall is not injured (stable fractures) are the most frequent among ejected pilots. Fractures with injury to the posterior wall are rare. Some organizations (the RAF, for example) have not observed any injuries of this type in 10 years of practice.

2.2.3. Fractures with Intact Posterior Wall (stable fractures) /46

In the large majority of cases the posterior wall remains intact. This fact is obvious in localized x-rays. Frontal and sagittal tomographs confirm the impression given by the reading of standard x-rays. A side view inflection will generally show normal spacing of the spinous processes, thus confirming the intactness of the ligaments.

The vast majority of cases involve fractures of the vertebral body.

These will be described, giving consideration in turn to:

-- the shape of the body,
-- the appearance of the outlines of facets and angles
-- the density and structure of the bony area,
-- injuries of the posterior arch,
-- displacements and postural disturbances
-- related injuries (disks, ligaments and soft parts),
-- concurrent injuries.

Shape of Body

Cuneiform compressions are the most frequent, lateral compressions being more seldom in occurrence.

An anterior cuneiform compression is manifested by a decrease in the height of the vertebral body, localized in its anterior part.

One or several vertebrae are injured. The same appearance of anterior cuneiform compression is found in all the fractured vertebrae.

Profile x-rays, which are the most informative, reveal the degree of compression. In most cases the flattening is slight. Frontal x-rays sometimes reveal an enlargement of the vertebral body.

Lateral compression occurs more seldom. In a frontal x-ray, the height of the vertebral body is asymmetrical within the frontal plane.

Appearance of Angles and Outlines of Facets /47

The anterior outlines are frequently irregular. In compression fractures the anterior corner projects into the vertebral outline. The fracture line is seldom visible; thus Watson-Jones speaks of enclosed compression fractures.

In a number of cases the anterosuperior wedge is torn away and the fracture line which is thus visible is irregular or rabbeted. The anterior edge of the vertebral body is deformed into an obtuse angle.

Compression fractures are accompanied by effraction of the anterior part of the facets. In more than 75% of the cases only the upper facet is injured. In severe trauma there will not infrequently be related injuries of two vertebral plateaus (especially in difficult landings).

Density and Structure of Bony Area

In fractures examined a short time after ejection, there is no extensive change in the density or structure of the bony area. In some cases the injured portion may have a more or less condensed appearance.

Injury to the Posterior Arch

The posterior wall is intact, but related injuries of the posterior arch may be encountered. These usually involve the transverse processes, which show lapses in continuity.

Displacements and Postural Disturbances

In simple compressions leaving the posterior wall intact, the immediate effects include neither vertebral displacement nor postural problems.

Related Injuries

The disks and ligaments are generally not affected in anterior cuneiform compression. However, this is not always the case. The nucleus pulposus may collapse the vertebral facet which supports it.

Injury to a disk may correspond to severe compression. It /48
is usually the subjacent disk which is injured. These injuries sometimes coincide with simple rupture of the facet without compression. The median or anterior portion of the facet thus forms a broken line in an x-ray taken in profile.

The isolated disk injuries occurring in some cases are manifested by simple pinching of the disk without any injury to the bone.

A disk ruptured in this way will not separate from the bone. This type of disk injury results in the more or less rapid onset of arthrosis.

Concurrent Injuries

These injuries, which are frequent in severe trauma, basically include:

-- reflex aerocoly,
-- other traumatic injuries, fractures of the limbs and the cranium.

2.2.4. Fractures with Injury to the Posterior Wall (unstable fractures)

The frequency of these fractures is very slight in comparison to the preceding category. This type of fracture is much more serious, since it exposes the subject to nerve injury (depending on the stage, paraplegia or cauda equina syndrome). This requires surgical treatment and the use of a cast.

Some indication of the injury to the posterior wall may already be seen in profile x-rays. These x-rays permit a study of the vertebral fragments and measurement of the degree of scoliokyphosis. Tomographs will reveal the number of individual vertebral body fragments and the orientation of fracture lines. Their use makes it possible to determine the degree of injury to the posterior wall. These types of fractures may be divided into two classes:

-- comminuted fractures in which the vertebral body is dislocated,

-- fracture-dislocations in which the fracture line passes through both the posterior arch and the vertebral body, obliquely from back to front and top to bottom.

The diversity of these injuries makes it difficult to per- /49 form any systematic study.

These fractures will be studied under the same plan as that used in the preceding section.

Shape of Body

In comminuted fractures, the vertebral body is shattered. There is general deformation of the body of the broken vertebra, creating an angulation with the acute angle of the spine at this level. Anterior fragments and lateral fragments are expelled.

The crushed vertebral body is generally enlarged in frontal x-rays. In profile, the anterior fragments clearly project forward, while the more or less trapezoidal posterior fragments jut to the rear.

In fracture-dislocations, the fracture line, continuing that reaching the posterior arch, travels through the body in a direction which is usually oblique from back to front and top to bottom, generally passing through the upper third of the body. It divides the injured vertebra, like a long bone, into two fragments, an upper and a lower fragment. The upper fragment has moved forward in relation to the upper fragment.

The Outlines of the fragments in tomographic cross sections are distinct.

Density and Structure of Bony Area

Usually normal, these may be altered by a process of condensation.

Injury to the Posterior Arch

In comminuted fractures, due to the shattering of the vertebral body and the considerable displacements, the posterior arch is always injured, particularly at the level of the articulars, which are dislocated or fractured.

In fracture-dislocations, the oblique line continues, simultaneously travels through both arches and dislocates the articular processes, and reaches the pediculi, the isthmi or one of the posterior attachment or stabilization systems.

In both types of fractures, displacements and postural /50
problems are considerable.

Most orthopedic surgeons emphasize the importance of measuring the degree of scoliokyphosis, which is a significant factor in caring for the patient. This measurement is performed in several ways:

-- by the angle between the two upper and lower facets of the injured vertebra,

-- by the relationship between the height of the posterior edge and that of the anterior edge of the injured vertebra,

-- by the general configuration of the spinal axis, the line passing through the anterior edges generally describing a regular curve with a wide radius. The angle resulting from the plotting of this line in cases of spinal fracture accurately measures the degree of compression, that is, the degree of scoliokyphosis.

The latter method is preferable.

Related Injuries

In these two types of fractures:

-- The disk subjacent to the fractured vertebra is broken or destroyed. Several disks may be injured simultaneously; x-rays may show them to be obliterated or pinched.

-- The interspinous ligaments are very frequently torn, and the soft perirachidial parts are severely injured.

-- Injuries to the disk and interspinous ligaments which do not heal spontaneously will have serious repercussions on subsequent development and problems stemming from the injury, and also on the immediate development. This is a factor in secondary mobilization after reduction.

Concurrent Injuries

Since the trauma is generally severe, the patient will usually have several fractures (limbs, skull, ribs, etc.).

2.2.5. Isolated Fractures of the Posterior Arch

These are rarer in occurrence.

Fractures of the Processes /51

Projecting flat processes such as the spinous or transverse processes, normally protected by their muscular cushioning rather than by their strength, are exposed in the case of direct impact (upon landing in all cases).

Fractures of the Spinous Processes

Generally resulting from direct trauma, these are located principally in the cervicodorsal region, accompanied by displacement of the distal fragment and bulging of neighboring soft parts, indicating the existence of a hematoma.

Isolated fractures of the transverse processes also occur in pilots as a result of direct trauma.

These are located almost exclusively in the lumbar region. The distinct fracture line is usually located on the narrow end of the process. There may be only one line, or it may be present on several vertebrae or bilateral.

Movement in the lumbar area controlled by the lumbar quadratus occurs in a downward direction as a general rule; this sudden contraction contributes to the fracture.

Bulging of the psoas indicates the existence of a hematoma.

Fractures of the Articular Processes

These fractures, which seldom occur in isolated form, result from a heavy torsion stress with lateral flexion of the trunk (landing accident). The thin and extremely fragile articular processes are likely to break and come out of alignment when they no longer overlap by more than a few millimeters.

These fractures, which are extremely difficult to diagnose by x-rays (requiring many different views and the use of tomography), are frequently discovered only at a late stage of painful pseudarthrosis.

2.2.6. Special Clinical Forms /52

These are basically fractures of the last five cervical vertebrae occurring in the course of the landing phase. Identification of these traumatic injuries, combining fractures and dislocations, is facilitated by the small dimensions of the last five cervical vertebrae, their wide range of movement, and the presence of relatively thick disks. The subjacent vertebra is pulled by the weight of the head, which falls forward.

Injuries to the nerves, spinal cord and radiculae, which may exist in the absence of visible radiological symptoms, are extremely frequent and extremely serious (tetraplegia).

Fracture-Dislocations constitute the most frequent anatomic form of injury to the last five cervical vertebrae. The upper rostrum of the articular process of the subjacent vertebra is fractured. Instability appears.

Fractures resulting from a hyperextensive movement of the head include:

-- bilateral fracture-dislocations with anteroposterior displacement,

-- unilateral fracture-dislocations with in-place rotation of a vertebral body,

-- dislocation with rupture of the vertebral ring, the simplest type being fracture of the pediculi.

Fractures of the Anterior Body of the vertebra occur less frequently in pilots. These generally result from a hyperextensive movement (case observed by reporting investigators not included in this study). Rupture of the anterior and inferior body of the vertebra may appear to be only a minimal bone injury, but it is generally accompanied by severe discoligamentary injuries, especially with conjoint occurrence of fracture of the articular or spinous processes.

Dislocations and Subdislocations of the Cervical Region, which occur very frequently in traffic accidents, have not been observed in this study.

3. Differential Diagnosis (Fig. 16) /54

A differential diagnosis of vertebral fractures may be made for a large number of infectious spinal diseases, benign or malignant tumors, and dysplasia or dystrophy. In these cases, the radiologist receives a general orientation from the overall clinical symptoms and laboratory tests. In regard to healthy vertebrae one should be on the alert for:

-- morphological variations which may be confused with vertebral fracture,

-- changes due to a congenital abnormality or disturbance in the development of the vertebral body, the neural arch or the disk-vertebra unit.

3.1. Morphological Variants

Vertebrae will sometimes show variations in their morphology. The most frequent variant is the vertebra with cuneiform tendency. Knowledge of this variant is of fundamental importance in the ability to confirm traumatic etiology.

Definition of vertebra with cuneiform tendency. In statistical studies of vertebral bodies with a cuneiform tendency, a large number of investigators have chosen to consider the following in defining the cuneiform tendency of a vertebra:

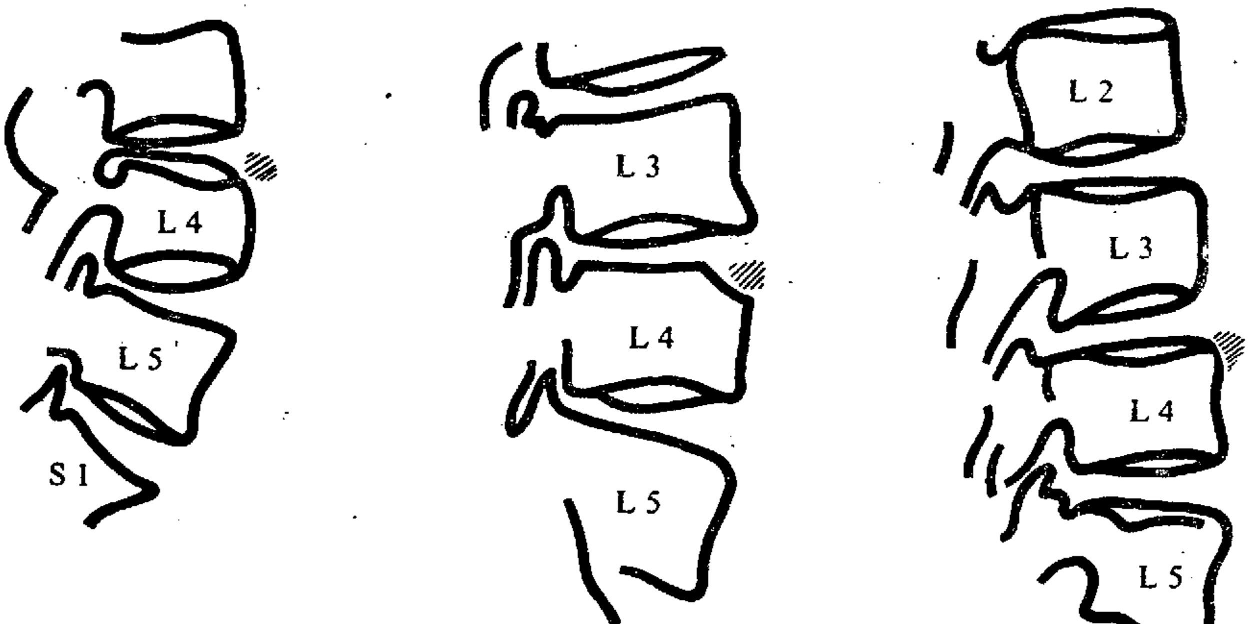
-- in frontal view, differences in height of more than 2 mm from one side to the next,

-- in sagittal view, differences of more than 3 mm for L1 and 2 mm for the other vertebrae between the anterior and posterior edges.

The vertebra with cuneiform tendency possesses regular undestroyed bodies without any change in structure or density.

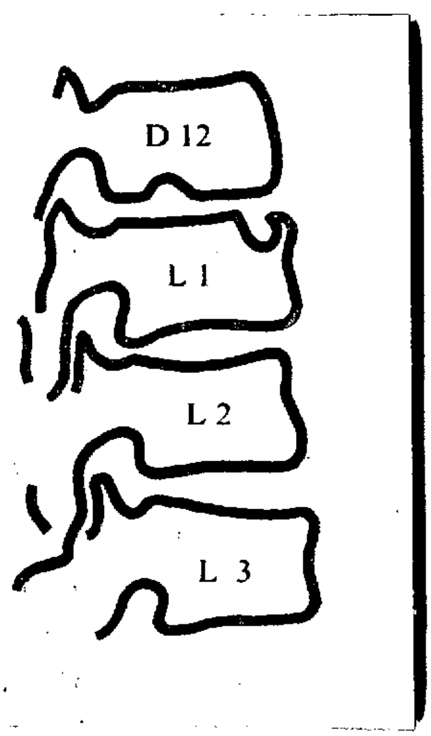
The different vertebrae with cuneiform tendency.

Morphologically variant vertebrae occur frequently. These vertebrae are preferentially found at the center of the natural flexures.

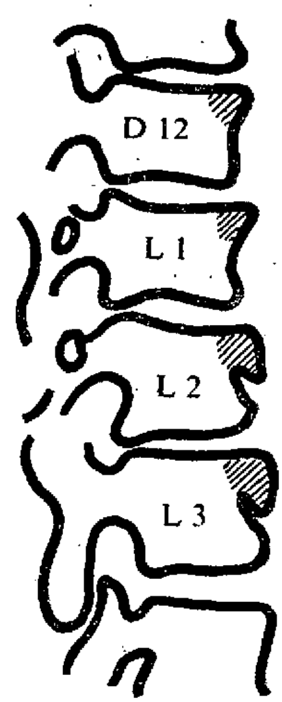


/53

The anterior bodies (after Decoulx)



Retromarginal hernia



Recent multiple fractures

Fig. 16.

D5, D6, and D7 for the dorsal column,

D11, D12 and L1 at the dorsolumbar hinge.

Changes Due to Developmental Disturbances

The absence of fusion of the vertebral bodies
the adult: the "paradiscal" defect cited by British investigators.

This is a frequent abnormality. It is manifested in side-view x-rays of the vertebrae of children by a distinct line located at the insertion of one or several corners. Such images are common up to ages 21-22. At this age these small detached triangular fragments become fused with the vertebral body. Their persistence in the adult indicates a developmental disturbance which has prevented normal fusion.

The degree of separation of the fragment from the vertebral body varies: usually it is complete, and more seldom incomplete. It is frequently located at the anterior and superior body of the vertebral body, and more seldom at the anterior inferior body. It is rare that the detached anterior body will be exactly contained within the outline of the body. It will either be small, atrophied and even punctiform, or will be too large due to excess growth and will extend beyond the outline of the vertebra.

Characteristics differentiating the absence of fusion of the vertebral body in the adult from anterior marginal fracture are the following:

-- it is separated from the vertebra by a distinct and regular rectilinear line which is much different from the irregular, notched line of marginal fractures,

-- a paradiscal defect remains consistently the same without any tendency to become fused. A marginal fracture, in healing, produces an irregularity in the curvature of the anterior surface of the vertebral body.

Anterior Retromarginal Hernia

This is a notch in the superior or inferior vertebral facet of a dorsal or lumbar vertebra.

In a side-view x-ray, it is seen as an anterior retromarginal notch inclined slightly backward, but whose anterior part, on the other hand, is usually vertical and may even be inverted slightly to the rear.

In a frontal x-ray, its lengthwise appearance is that of a pole or cup. /56

This notch may be accompanied by an overall increase in the height of the intervertebral disk. In some cases an osteophytic excrescence may be noted in front of the vertebral edge.

This type of retromarginal hernia is a variety of intra-spongy hernia which occurs at the level of an anterior zone of least resistance in the spongy tissue of the vertebra. It is frequently observed in sequels to Scheuermann's disease. It generally occurs in conjunction with other characteristic symptoms of the disease, but its occurrence may be isolated.

3.2. Congenital Abnormalities

There are many types of these abnormalities and they will be cited very briefly. They are relatively easy to recognize.

Rare abnormalities include:

-- anterior rachischisis, which should not be confused with a sagittal fracture,

-- congenital vertebral block, which is much more regular in height and shape than traumatic block,

-- the persistence of Hahn's vascular slits, fine distinct lines which can be seen from the side passing through the center part of one or several undeformed vertebral bodies. The anterior portion of these distinct lines is especially sharp.

CHAPTER 4. TREATMENT OF SPINAL FRACTURES IN THE EJECTED PILOT /57

General Comments /58

Pilots are usually examined by a flight surgeon shortly after ejection and in most cases are sent to an x-ray clinic, and hospitalized and treated in an orthopedic surgery department.

General Therapeutic Principles do not differ from those followed in current practice, for example after occupational, traffic or athletic accidents. A general outline will be given corresponding to the preferences of various schools of orthopedic surgery.

Simple Compression Fracture

-- Strict bedrest on a hard surface, immediately.

-- Early rehabilitation to the extent that the fracture is stable and not compound.

-- Pain does not seem to be a contraindication to rehabilitation.

-- Patient ambulatory at the end of 3 weeks.

Fracture with Enucleation

-- 4 to 6 weeks bedrest.

-- Rehabilitation beginning at a late stage since this type of fracture is more painful (beginning with the 3rd or 4th week on the average).

Compound Fractures

-- If there is no regression in the first hour following the fracture, neurological complications in these cases are permanent.

However, surgical treatment is necessary to stabilize the fractures and permit easier nursing.

-- When there are neurologic complications, the fracture site should be stabilized by orthopedic or surgical means (particularly osteosynthesis). The technique used depends on the type of injury. /59

Multiple Fractures

-- Heavy compression sometimes results in changes in the sagittal posture, especially in the dorsal region.

The Length of Unfitness for Service, in view of the wide variety of the different types of spinal fractures which may be observed in ejected pilots, is difficult to determine with certainty. Two organizations have given precise responses to the editors' questionnaires (FAF, GAF).

NUMBER OF PILOTS WITH AVERAGE LENGTH OF UNFITNESS FOR SERVICE.

	Unknown	1 mo.	2-3 mos.	6 mos.	7-8 mos.	12 mos.	14-16 mos.	18 mos.	Permanent
GAF	1	2	2	-	6	1	2		0
FAF	3	4	5	5	-	1	-	1	1

Sequels to Spinal Fractures

Due to their frequency, these present problems to all physicians responsible for the medical surveillance of combat aircraft pilots.

1. Clinical Study

It was possible to divide injured patients into two categories:

+ injured subjects whose fractures remain unrecognized,

- subjects whose injuries are recognized and treated, but who show a delayed pain syndrome.

1.1. Subjects With Unrecognized Fractures /60

In most cases the fracture remains undetected due to the lack of any radiological testing, which justifies:

-- systematic performance of x-rays of the entire spine for every ejected pilot,

-- the use of a completely reliable x-ray technique, frequently complemented by tomography.

Secondarily, there is the onset of pain localized at a fairly precise point and aroused by assumption of a standing position or forward bending, and sometimes accompanied by radicular irradiations.

The laterovertebral muscular masses are atrophied: the mobility of the spinal segment involved is decreased. The spinous process is painful at this level.

In some cases x-rays reveal considerable vertebral deformations whose latency can only be considered surprising.

1.2. Subjects Whose Injuries Are Recognized and Treated, but Who Show a Belated Pain Syndrome

In these cases the subject complains of renewed pain at the end of several months or years.

The origin of these pain phenomena should be sought in the persistence of a muscular and ligamentary deficiency due to the incomplete functional rehabilitation of the patient, who will not always have understood the necessity for this treatment. Some pilots with fractures are subject to cervical or dorsolumbar pain during helicopter flight (U.S. Army).

2. Anatomicopathological Development of Fracture Site

Study of this development facilitates comprehension of the radiological image. Classification of fractures as stable and unstable forms is extremely valuable in describing the early development of vertebral body fractures.

2.1. Early Development /61

In stable forms, compression reaches a maximum at the outset. There is no risk of exacerbation. Movement is possible at an early stage.

In unstable forms, secondary displacements of bone, ligament or disk injuries, furthered by gravity, are possible at the least movement of the subject (transport, x-ray examinations on a table, or even x-rays taken with the patient remaining in bed). The immediate immobilization of the patient should remain in force until the injury begins to heal. A bony or fibrous callus or simple fibrosis of the soft parts will appear after a variable period of time (1 to 3 months).

2.2. Later Development

2.2.1. Bone Site

Vertebral fractures heal in a twofold manner:

-- formation of a callus at the level of the destroyed spongy tissue,

-- healing by periostic callus, a phenomenon which is certainly less marked in these cases than in fractures of the long bones, and whose occurrence here is denied by some investigators. This consolidation is manifested in x-rays by the appearance of small calcified fragments detached from the anterior ligament, and by formation of orteophytes along the margin.

The False Kummel-Verneuil Syndrome

Prior to the availability of x-ray techniques, Kummel and Verneuil described a syndrome characterized from a clinical standpoint by initial trauma with attenuated and short-lived clinical symptoms:

-- by an asymptomatic interval,

-- by the secondary onset of scoliokyphosis with resumption of pain.

They related this clinical pattern to secondary vertebral compression due to post-traumatic osteoporosis. However, in subsequently reported cases of this syndrome, the absence of x-rays performed immediately after the trauma (during the following 24 hours) makes it impossible to retain a single undebatable case of progressive secondary compression.

H. Mangin, R.P. Delahaye, and R. Buchet have reviewed files on 102 cases of spinal trauma occurring in the course of radiological examinations following aircraft accidents from 1951 through 1963. Results of x-rays performed during the 24 hours following the aircraft accident were compared with those performed in 1962 or 1963. There were 16 compression fractures and 86 traumas without any initially detectable injury. /62

In no cases did these investigators observe any vertical compression subsequent to the various tests performed. They were able to state that the techniques used, employing standard x-rays and tomographs, were extremely reliable, given that no fractures went undetected.

At present most orthopedic surgeons and radiologists concern themselves with the traumatology itself, assuming that post-traumatic vertebral compression -- the anatomic basis of the Kummel-Verneuil syndrome -- is not present.

Thus we might indicate the necessity of performing systematic x-rays on ejected pilots, even if the clinical symptomatology is absent. There is no need to emphasize that this examination should be technically perfect and that valuable information can be supplied by tomographic examination in questionable cases.

2.2.2. Disks

An injured intervertebral disk never recovers its original structure. Deprived of its elasticity, it ceases to serve as a hydraulic damper of spinal movements. Post-traumatic calcification of the nucleus pulposus is rare. On the contrary, rather than undergoing densification and ossification, the disk becomes deformed: it thus permits the vertebral bodies to alter their positions in relation to each other. In exceptional cases it may degenerate and disappear completely (traumatic block).

3. Radiological Appearance of Sequels

3.1. At the Level of the Bone Sites

3.1.1. Case of Simple Compression Fracture

Cuneiform compressions persist. There is frequently a discrete densification of the compressed body, but it retains its regular shape. This is the phenomenon of reassimilation. In most cases the intervertebral space retains its normal height.

3.1.2. Case of Compound Fractures With or without Injury to the Posterior Wall

Very early marginal osteophytosis indicates the severity of injury to the disk. The degree of pain -- which is of frequent occurrence -- simultaneously depends on the arthrosis and on deficient tonus of the laterorachidial musculature.

3.1.3. Failure to Heal

The onset of pseudarthrosis appears in x-rays as the persistence of a fracture line; this phenomenon is very frequent in the vertebral processes.

Pseudarthrosis of the spinous processes, transverse processes and articular processes should be pointed out in this connection.

3.2. At the Level of the Disk and the Peridiscal Tissue

The following distinctions will be made as a function of the anatomicopathological course:

3.2.1. Preferential Sites of Pinching or Gaps

These tend to return the spine to an upright position. They can be accurately detected only by the use of radiodynamic methods.

3.2.2. Peridiscal Calcification

This is generally accompanied by pinching of the disk. One may observe:

-- marginal osteophytosis appearing in the form of a dense proliferation of vertebral edges and angles with regard to the injured vertebra. The subjacent vertebra will usually provide a supporting surface;

-- extradiscal synostosis. In front of or to the side of the vertebral body there is a bony bridge spanning the disk and fusing two or three vertebrae, spontaneously forming a virtual vertebral graft.

These phenomena, however, are observed in the absence of any change in the height of the intervertebral spaces. The role of hemorrhages particularly affecting the peridiscal space should be kept in mind in considering the origin of these synostoses.

The disk may disappear completely. In these cases there is fusion of two neighboring vertebral bodies. This phenomenon is relatively rare.

3.3. Displaced Vertebrae

The disk may become deformed, permitting the vertebral bodies to shift in relation to each other. At the level of the lumbosacral hinge, the anatomic structure lends itself to slipping of the fifth lumbar vertebra in front of the sacral facet in cases of traumatic rupture of the vertebral isthmus (rare). Usually the trauma reveals pre-existing spondylolisthesis.

4. Sequels to Ligamentary Injury

This concerns the failure to heal of interspinous ligaments. The late onset of pain is frequent in the course of spinal fractures. Postural changes exacerbated by the deficiency of the laterovertebral musculature offer more explanation for the persistence of pain than for the onset of arthrosis. The significant results furnished by kinesitherapy definitively show the large extent to which this pain is of muscular origin.
In conclusion:

The most frequent final result of spinal fractures is thus arthrosis.

Whatever spinal region is considered, radiodynamic symptoms are present at a more or less early stage.

The problem of repeated ejections: Mention should be made of the possibility of repeated ejections with spinal fractures for the same pilot. It appears difficult to offer any general treatment procedure for this problem, and the specialist must make his evaluation as a function of orthopedic and psychological criteria, taking into account the length of service of the pilot, his aeronautical experience and his motivation.

CHAPTER V. PERSONNEL SELECTION /65

1. Admission of aircrew
    1.1. Radiological test of fitness
    1.2. Concepts of normality
    1.3. Static disturbances. Broadened definition of normality
    1.4. Fitness and congenital abnormalities
        1.4.1. Discosomatic abnormalities
        1.4.2. Abnormalities of the posterior arch
        1.4.3. Transitional abnormalities
    1.5. Acquired diseases and fitness

2. Re-examination consultations
    2.1. Fractures of the spine
        2.1.1. Fractures of the dorsolumbar region
        2.1.2. Fractures of the cervical region
    2.2. Arthrosis
    2.3. Vertebral osteoarthritis
    2.4. Rheumatoid pelvispondylitis
    2.5. Surgical intervention
    2.6. The problem of repetition

Study of the harmfulness of ejections and statistical /66
analyses have objectively shown that the spinal column is placed under severe strain during the abandonment of distressed aircraft.

It thus becomes necessary to determine the standards for fitness of the spine for the use of ejectable seats.

These conditions for fitness are viewed in two very specific aspects:

-- fitness for acceptance of aircrew,

-- fitness during re-examination consultations and after aircraft accidents.

1. Acceptance of Aircrew

There are no commonly held views among NATO countries on whether or not a systematic radiological examination should be performed on the spinal column during admission examinations of aircrew.

	Systematic Radiological Examination	Remarks
USAF	No	Performed if there are antecedents or if there is reason for clinical doubt
U.S. Army	Yes (?)	To detect spondylolysis or spondylolysthesis or if there are clinical standards
FAF	Yes	Entire spine, admission only
GAF	Yes	Entire spine (upon admission and 5 years later)
HAF	Yes	Dorsal and lumbar regions
IAF	Yes	Entire spine
RAF	No	

1.1. Radiological Test of Fitness /67

Currently all candidates for aircrew personnel in the FAF are required to undergo a radiological examination of the entire spine.

This examination consists of seven x-rays taken at standard angles:

-- front and side views of the cervical region,
-- front and side views of the dorsal region,
-- front and side views of the lumbar region,
-- front view of L5.

These x-rays are taken standing. Special care should be taken in positioning the subjects. In some cases dynamic examination from the side is indispensable for studying the persistence of a congenital abnormality.

The confidential interpretation (not communicated to the candidate) is extremely detailed. It must contain all anatomic variants and congenital abnormalities, even those which are discrete.

This reference file has a threefold purpose:

-- elimination of serious injuries capable of modifying the strength of the vertebrae and incompatible with flying practice;

-- study of occupational pathology;

-- possible comparison with x-rays taken after trauma (ejection, flying accident, etc.).

These factors comprise a viewpoint which is shared by specialists in other European air forces. Some organizations, however, do not consider radiological examination of the spine a requirement, for the following reasons:

-- increased radiation doses for the aircrew,

-- low likelihood of the necessity for ejection.

In our opinion this position is not logical for the following reasons:

-- the existence of a large number of acquired diseases or congenital abnormalities without clinical manifestations, /68

-- the absence of a reference file, which is always useful in safeguarding the interests of the government and the pilots from a medicolegal standpoint,

-- lack of the opportunity for serious study of the occupational pathology of aircrews,

-- lack of information on the development of normal radiological images.

1.2. Standards of Normality

Frequently regulations require that every aircrew candidate be in perfect clinical and radiological condition. The definition of a normal spine, however, remains problematic. Some consideration should be given to this question since any fixed set of regulations produces the risk of eliminating too many candidates, since normality factors may themselves vary.

In front view, the line of the spinous processes follows the vertical descent of the external occipital protuberance to the tip of the coccyx.

In side view, the vertical line passing through the large trochanter intersects L1 or L2 at its midpoint and ends tangential to the anterior surface of the atlas and the axis (theoretically normal posture).

This definition seems to be particularly valid for examination in dorsal decubitus.

In standing position, very few subjects meet these standards.

Some investigators (specifically Testut, Schmorl and Junghans) consider the frequent minimal dorsal inflection with right convexity to be a normal variation (classical normality).

Others consider it to be due to greater development of the trunk musculature on the right side, appearing at approximately age 6. Still others consider it due to the presence of the aorta.

A study dealing with 2500 files of spinal x-rays performed from 1969 to 1971 in the course of admission examinations for FAF aircrews has facilitated the study of normality and decisions as to fitness.

TABLE 16. DISTRIBUTION OF SPINAL ABNORMALITIES FOUND IN A HOMOGENEOUS FRENCH POPULATION AGED 19 TO 23 (French Air Force).

1. Postural Disturbances			/69
a) In the frontal plane	1867	74.68%	
-- scoliotic position	518	20.72%	
-- scoliosis without pelvic d sequilibrium	839	36.56%	
-- scoliosis with pelvic d sequilibrium	510	20.40%	
b) In the cervical region	471	18.84%	
-- inflection	329	13.16%	
-- dysharmony	95	3.80%	
-- dysharmony + inflection	47	1.88%	
2. Anatomical Variations			
-- Anterior cuneiform appearance	191		
L1	102	4.08%	
L2	35	1.40%	
D12	30	1.20%	
Other vertebrae	24		
3. Sequels of Scheuermann's Epiphysosis	302	12.08%	

4. Congenital Malformation

a)	Dehiscence of the posterior arch	482	19.82%
	S1	437	17.48%
	L5	23	
	S2	12	
	C5	2	
	C6	1	
	C7	1	
	D1	1	
	C1, C2, C3 (related)	1	
	Various	4	
b)	Transitional abnormalities	237	9.48% /70
	L5		
	Hemisacralization	37	1.48%
	Sacralization	52	2.08%
	Sacralization + Neoarticulation	20	0.80%
	S1		
	Hemilumbarization	26	1.04%
	Lumbarization	102	4.08%
c)	Isthmic lysis	114	4.56%
	* With spondylolysthesis	76	3.04%
	-- of L5 on S1	68	2.72
	-- of L4 on L5	4	
	-- of S1 on S2	3	
	-- of C6 on C7	1	
	* Without spondylolysthesis	38	1.52%
	-- L5	31	
	-- L4	4	
	-- S2	3	
d)	Congenital blocks (aside from transitional abnormalities)	26	1.04 %
	- C2, C3	10	
	- C3, C4	3	
	- C4, C5	1	
	- C5, C6	2	
	- C6, C7	4	
	- C7, D1	2	
	- D9, D10	2	
	- D10, D11	2	

e) Rarer abnormalities /71

-- Anterior body	28
-- Anterior retromarginal hernia	46
-- Outline of cervical rib	9
-- Detached nucleus:	
* Of spinous process of C2	1
* Of spinous process of C3	1
* Of transverse process of D1	1
* Of transverse process of L1	4
* Of transverse process of L2	1
* Of transverse process of L3	1
* Of transverse process of L4	1

f) Kimmerle's abnormality (arcual foramen)	162	6.48%

These extremely homogeneous statistics show the high frequency of spinal abnormalities.

In addition, they show that only a very low number of subjects meet the criteria for normality.

As a result, and taking into account the large number of spinal abnormalities with no actual or practical significance, the current definition of normality should be reconsidered.

1.3. Postural Disturbances. Broadened Definition of Normality /72

Postural disturbances represent the majority of recorded abnormalities.

Postural disturbances in the frontal plane: 1867 cases (74.68%) have been recorded.

These are of two types:

* scoliotic position, simple discrete lateral inflection without rotation of the vertebral bodies, encountered in 518 cases (20.72%);

This falls within the framework of classical normality.

* scoliosis: There are 1349 cases of scoliosis, 839 of them (33.56%) without disequilibrium of the pelvis, and 510 (20.40%) with pelvic disequilibrium.

Both cases usually involve slight scoliosis with minimal curvature and very discrete rotation of the vertebral bodies. There is no pain symptomatology.

The growth of the subjects is completed and it does not seem likely that the scoliosis will be exacerbated (especially in cases lower than 15°C).

Adopting the criteria of classical normality, there remain 1349 subjects with scoliosis.

It was difficult to accept that nearly 50% of the subjects could be "abnormal."

Normality should represent the majority of supposedly healthy subjects (according to Gaussian data). The maximum angle of scoliosis compatible with the conditions of ejection and piloting of combat aircraft is fixed at 15°, which corresponds to USAF and GAF regulations.

In the 2500 spines examined, the angle of scoliosis was greater than 10° in only 5.4% of the cases.

Cervical postural disturbances were frequent and were almost always extremely minimal (471 cases, 18.84%).

These may be evaluated only on the basis of the x-ray views taken, under very rigorous technical conditions.

1.4. Fitness and Congenital Abnormalities /73

Major congenital malformations with heavy clinical disturbances or obvious modifications in posture will not be considered.

These unquestionably result in unfitness.

Consideration will be given only to a given number of abnormalities which show no clinical manifestations and are revealed only by x-ray examination.

Some malformations which do not modify the strength of the spine should not result in the subject being designated unfit.

Others which show risk of weakening the spine may be taken as disqualifying factors: the subject will be designated unfit only after study of the type of malformation and its site in relation to the area likely to undergo trauma (median dorsal region and dorsolumbar hinge for combat aircraft pilots).

The object is to avoid disqualifying highly motivated subjects, while still remaining within normal safety restrictions.

I. Discosomatic Abnormalities

Consequences of developmental problems in the dorsal cord, these result from defective segmentation and a vascularization disturbance.

When not fatal, these abnormalities entrain more or less severe deformations and disequilibria.

* The congenital vertebral block represents partial fusion of one or several vertebrae.

An isolated problem, it does not result in any change in height or curvature.

It most frequently appears in the form of a C2-C3 block and sacralization of L5 on S1.

Injury to the cervical region is rare in aeronautical medicine. If the block is isolated and is not accompanied by any modification of posture or the dynamics of the cervical region, the subject may still be designated fit.

Identical principles hold for lumbar or dorsal sites. /74

Blocks of three vertebrae or more result in unfitness.

* Vertebrae with cuneiform tendency, frequent variants (191 cases), are due to poor pressure distribution.

These are found at the center of the natural curvatures (D6, D12, L1).

In the opinion of Delmas, these are capable of altering the strength of the posterior wall. This observation is significant since these vertebrae are located in frequently injured zones. The research undertaken has been too recent to formulate definitive conclusions.

The subject is still deemed fit for service.

* Lack of fusion of the vertebral bodies.

This infrequent abnormality (1.8%) indicates a developmental disturbance. Normally, fusion takes place at approximately 21 to 23 years of age, and this configuration is normal in children.

It is most frequently found for a single vertebral body (especially L1-L2).

Some investigators consider that this abnormality, even when isolated, will weaken the disk and result in precocious degeneration. This opinion is not shared by a large number of radiologists and rheumatologists.

The subject should be designated fit.

The problem is different when the anterior body is associated with sequels of epiphysosis or anterior retromarginal hernias.

* Schmorl's furrows, due to abnormal discal expansion, are a cause of unfitness when they occur in multiple regions and are related to epiphysosis sequels.

An isolated Schmorl's furrow should not be an eliminating factor.

* Anterior retromarginal hernia. This is a characteristic notch in the vertebral facet, generally the upper facet, of a dorsal or lumbar vertebra. /75

It frequently accompanies sequels of epiphysosis, but it may also be isolated, which does not make the subject unfit for service.

* Rare malformations: sagittal dehiscence of a vertebral body and supernumerary hemivertebrae are reason for unfitness.

2. Abnormalities of the Posterior Arch

These result from disturbances in the development of the neural canal. They may be accompanied by meningeal-spinal cord malformations, but minor changes without clinical manifestations are frequent.

* Isolated dehiscence of the posterior arch: The most frequent malformation (482 cases, 19.82%).

This is frequently found at the lumbosacral hinge.

This asymptomatic phenomenon does not change the solidity of the spine.

It should not be a basis for unfitness (FAF, HAF, GAF, IAF, USAF).

* Dehiscence of the isthmi or spondylolysis. This phenomenon, which is relatively frequent and is usually bilateral, commonly involves the last lumbar vertebrae.

In countries which require x-rays for admission, spondylolysis is a disqualifying factor. One may question whether this attitude is excessively severe; in some cases spondylolysis does not develop, even if there is discrete spondylolysthesis, and after age 21 it generally remains static.

3. Transitional Abnormalities

These are frequently observed. They are generally located at the level of the hinge zones.

There are basically two types of transitional abnormalities of the lumbosacral region: sacralization of L5 and lumbarization of S1.

Sacralization of L5 is an abnormal development of the transverse processes of L5, which tend to become articulated or unite with sacral wings. /76

This more or less marked hypertrophy may be unilateral or bilateral.

It does not result in unfitness. The lumbosacral hinge is not an area of possible trauma in ejections.

Lumbarization of S1 is manifested by the absence of sacral wings at the level of S1 and the presence of long thin transverse processes coming into contact with the iliac bones.

Here again, the subject is customarily designated fit.

1.5. Acquired Diseases and Fitness

All acquired diseases of tuberculous osteoarthritic or or staphylococcic type, arthritis (rheumatoid pelvispondylitis) and angiomas are eliminating factors.

The USAF permits acceptance with cured spinal fractures if the trauma has occurred more than 1 year earlier, if there is no symptomatology and if the height of the vertebral body is compressed no more than 25%. This position is not unanimously held, but in our opinion it is quite rational except in the case of cervical sites.

Sequels to Scheuermann's disease (spinal growth dystrophy), if they are significant, should be considered a basis for disqualification. The editors have been very disturbed by the opinions of of various organizations: most consider these sequels to be disqualifying factors. In our opinion, some of these sequels, which do not weaken the vertebral structure and do not increase the natural dorsal kyphosis, are compatible with fitness.

In conclusion, it appears that the positions of specialists on this matter are too severe in disqualifying fighter pilots (fitness for ejectable seats). Ejection actually occurs very rarely in flying service, and some of the rules currently in force as a function of the number of candidates and the needs of the organization may be made more flexible without additional spinal risk.

2. Re-examination Consultations /77

Any injury may weaken the spine and sensitize it to the effects of various flight stress factors. Some of these factors are usual and inherent in flight (vibration, long-term acceleration), and others are accidental, such as ejection, first of all, or crashes, more seldom in occurrence, subjecting the skeleton of the pilot to considerable force applied for a very short period of time. The problem of continuing to designate aircrew personnel as fit or disqualifying these personnel occurs after any medical or surgical spinal problem.

The spinal column consists of a skeletal, ligamentary and muscular assembly extending from the head to the pelvis. It is a virtual organ with the functions of support, shock absorption, protection of the spinal cord by preserving the spinal roots in emergencies, and mobility, related to the relative stability of the respective relationships of the components of which it consists.

This aspect of fitness is thus very different from that of acceptance. There is no precise and typical line of procedure. Each patient is a special case, and frequently decisions can be made only by medical and surgical collaboration.

2.1. Fractures of the Spine

These extremely frequent spinal injuries occur as the result of various traumas: highway accidents, aeronautical practice, sports. Whatever their etiology may be, the problems of fitness posed by the existence of these injuries are identical and sometimes extremely difficult to solve.

2.2.1. Fractures of the Dorsolumbar Region are observed in aeronautical practice (ejection, especially parachuting). They very frequently modify the solidity of the spinal column, and the decisions to be taken depend on the type of fracture.

The fractures fall into two classifications: comminuted fracture and simple compression fracture.

Comminuted Fracture of the Dorsolumbar Vertebrae

A series of basic findings revealed by R. Watson-Jones should be reviewed. When the anterior edge of a vertebral body has penetrated a fractured body, the spine was in hyperflexion at the moment of trauma. In these cases the interspinous ligaments are torn and the apophysic or interapophysic joints are frequently dislocated. The upper and sometimes lower disks are injured. These fractures are of unstable type. In the opinion of R. Watson-Jones, trauma producing an isolated dislocation, compression of the bone, ruptured disks, torn ligaments, fractured pediculi, interarticular dislocation, partial destruction of the anterior vertebral foramen or compression of the nerve roots will probably entrain the persistence of severe pain, even if the displacement is slight and reduction is maintained. These fractures are slow to heal. If conservative treatment is used, the patient should be kept flat for at least 6 months, sometimes 9 to 12 months. Synostosis of the vertebral bodies and ossification around the articular processes appear only at a late stage. Pain, discomfort and a sensation of weakness will last a very long time. Functional cures of serious comminuted fractures are observed only after several years.

This is why an attempt is made to accelerate this cure by the use of surgical procedures encouraging the fusion of the spinous processes and the vertebral laminae.

The decision for the specialist is simple: the injured subjects must be classified unfit for combat. The spine is no longer capable of tolerating, without risk of injury, the constant stresses of flight, much less accidental trauma (additional ejection, crash) to the spinous processes and the vertebral laminae. In addition, these subjects frequently suffer even under normal day-to-day conditions, since arthrosis occurs with a high frequency which varies with the statistics considered (60 to 70%).

The same is true of fracture-dislocations, which should permanently disqualify fighter pilots.

The rapid cure obtained is always facilitated by the use of exercises adapted to the clinical case. The pilot may be authorized to return to service in a short period of time due to the effective aid of the flight surgeon, who carefully monitors the pilot's return to occupational activities which are frequently intense (case of combat pilots). Daily vertebral exercises, indoctrination of the aircrew, and possible psychological support always facilitate the operational activity of these pilots. Here the flight surgeon plays an essential, fundamental and irreplaceable role. There is now an awareness of the benign quality of simple compression fractures, which was not the case 20 years ago. Overly severe decisions are no longer necessary due to improved knowledge of the course of these injuries.

2.1.2. Fractures of the Cervical Region

These are almost always due to highway accidents or athletic activity (especially diving). They frequently involve fracture-dislocations usually located at the level of the last five cervical vertebrae. More rarely, the atlas and the axis are injured.

There is a general tendency to eliminate these subjects and to classify them permanently unfit for service as fighter pilots. These injuries should be examined by the most thorough means of radiological testing. Modern tomographs permitting sections down to 1 mm have made it possible to examine these injuries closely, and an attempt to determine their influence on cervical dynamics should always be made when possible.

In cases of isolated fractures of the lateral musculature of the atlas not entraining any marked postural modifications and without clinical repercussions, the reporting organizations have given qualified unfitness decisions in two cases, granting permission for flight in light aircraft. There has been no cause to regret these decisions, since the injuries were very specific and relatively rare.

On the other hand, it has appeared to us that not all cases of fracture-dislocation of the atlas-axis, even when treated surgically, have permitted continuation of fighter-pilot activities. /80

Isolated fractures of the articular processes, which often go unrecognized in early radiological examinations, should result in less severe decisions, after study of the clinical and radiological pattern (particularly dynamic examination) and properly conducted rehabilitation. This is a typical example of graduated decisions by the specialist, who should synthesize the various medical and psychological elements and weigh the interests of the armed forces against those of the individual.

2.1.3. Fractures of the Transverse Processes of the lumbar vertebrae, frequently multiple and extremely painful, should permit the pursuit of normal aeronautic activity after treatment and rehabilitation of the musculature.

2.1.4. Trauma without Fracture

The absence of radiological lesions does not signify the absence of anatomic lesions of the intervertebral disks and the ligaments. The onset of pain or degeneration of the disks in the years following ejection or trauma is always possible. In cases of pilots who have continued to fly, it is frequently extremely difficult to determine the part played by the trauma incurred in ejection. Radiological tests 2 to 3 years after the accident are always useful for comparing the development of the vertebral condition in time and for detecting the onset of arthrosis. This difficult problem, which is being studied under the auspices of the AGARD, shows that it may be presumptuous to attempt to fix management procedure over a period of years, in view of the development of radiological techniques and changes in flying procedure.

2.2. Arthrosis (non-traumatic)

Isolated arthrosis, which frequently shows no clinical manifestations but is sometimes revealed by acceleration (aerial acrobatics), usually only necessitates bedrest. Moreover, there is no parallel relationship between radiological lesions and the clinical repercussions of arthrosis. Its presence rarely results in unfitness for service.

The course of arthrosis affecting several intervertebral /81
areas is fairly frequently marked by outbreaks of pain. Decisions of provisional unfitness facilitate the implementation of rational therapy (rest, medication, followed by muscular rehabilitation). It should be recognized that this type of arthrosis occurs most frequently toward age 40, which decreases the likelihood of its occurrence in fighter pilots.

2.3. Vertebral Osteoarthritis

a) The presence of tuberculous osteoarthritis of the spine (Pott's disease) is relatively easy to define. In all the organizations responding to the questionnaire, this disease is a disqualifying factor for acceptance of flying personnel. Since radiological examination of the spinal column was introduced as a requirement in the admission examination, no cases of Pott's disease have been observed.

The decision to judge active flying personnel permanently unfit for service will be taken not for functional reasons, but due to the presence of a tuberculous infection which always may appear, despite the use of effective medication.

The observation of a number of cases of tuberculous osteoarthritis in general practice, in non-aircrew subjects, has permitted us to formulate a very definite opinion. There can be no question of permitting continued aeronautic activity, even after non-mutilating medical treatment or limited surgical treatment. In our opinion, the only logical decision is to designate the pilot as permanently unfit, no matter what his length of service, experience and value may be.

b) Other types of osteoarthritis (melitococcic, staphylococcic) deserve special attention. All these types have little destructive effect on the vertebral bodies and have a tendency to produce ankylosis in a very short period of time. Here experience in regard to aeronautice practice is lacking. However, we have been able to confirm that once the spine has healed there is no unusual weakness. These opinions, of course, should always rest on a complete analysis of the clinical, laboratory and radiological pattern. We believe that in certain cases the pilot may still be deemed fit, taking into account the site and severity of the lesions observed.

2.4. Rheumatoid Pelvispondylitis (ankylosive spondylarthritis) /82

These lesions are located at the level of the sacroiliac vertebrae and the dorsolumbar hinge. The movement capability of the spine, which is preserved at the beginning, gradually decreases as a function of the onset of rheumatoid attacks. An attempt should also be made to determine other sites which will have an influence on the prognosis and the decision as to fitness:

-- sites in the respiratory tract with ventilatory deficiency of restrictive type linked to lesions of the costal-transverse joints and revealed by functional pulmonary testing;

-- cardiac sites: varieties of valvular cardiopathy, the most frequent of which are aortic deficiency, disturbances in auricular-ventricular conduction, and rhythmic disturbances;

-- ocular sites (iritis).

This chronic disease is usually compatible with appreciably normal aeronautic activity for a given length of time, with the help of carefully controlled treatment. The therapeutic method primarily combines vertebral and respiratory kinesitherapy and medication (acetylsalicylic acid and derivatives).

The decision as to the pilot's fitness should take into account the fact that this is a chronic disease which is suppressed for long periods by a non-dangerous treatment and is compatible with appreciably normal aeronautic activity (R. Pannier).

The onset of ankylosive spondylarthritis during a pilot's period of service leads to a much more complex policy, determined by various factors:

-- the course of the disease, which varies from one subject to the next,

-- the degree of functional impairment resulting from stiffening of the spine,

-- the existence of valvular cardiac lesions, electrocardiographic abnormalities, or ventilatory deficiency,

-- the necessity of using major inflammatory medication, exposing the subject to digestive complications.

A combat aircraft pilot may be retained as fit for an /83 extremely variable length of time depending on the course of the disease, kinesitherapy and the effects of medication; when the stage of complications is reached, the subject should be considered unfit.

2.5. Surgical Intervention

1. Laminectomy

The purpose of this surgical operation, which is performed only after careful consideration and in special cases, is to explore or decompress the spinal cord. It is followed by a high degree of instability, which will be increased to the degree that it involves several laminae and is extended laterally in the direction of the articular processes. Laminectomy (compression of the spinal cord, tumor) may in itself provide a reason for permanent unfitness.

In our opinion, flying personnel should be judged completely and permanently unfit for service after a laminectomy. There appears to be too great a risk in the course of aeronautic service of additional trauma to a spinal column which has already been weakened.

2. Cure of Discal Hernia

This is an operation which in most cases does not profoundly affect the solidity of the spine. Before making a decision, specialists should carefully analyze the contents of the operative report and should base their decision on the results of the clinical and radiological examinations. They should require that the operation involve only minimal laminectomy, that the diagnosis of discal hernia be confirmed, and that there has been satisfactory curettage of the intervertebral disk. There should be perfect clinical results with restitutio ad integrum. In particular, there should be no residual paresthesia or persistent pain. Tomographs should reveal remaining lesions of satisfactory appearance.

In our opinion, if there is considerable damage to the bones or ligaments, the pilot should be judged unfit for combat service. If the ablation of the discal hernia meets the previously described criteria, in some cases complete fitness may be maintained.

2.6. The Problem of Repetition of ejections for a single combat /84
aircraft pilot should be mentioned, but the number of cases observed remains too low to permit any general opinion. Study of this repetition of trauma is extremely interesting. So far it has been found that spinal fracture never recurs at the same vertebra, if there are no radical changes in posture. These cases should be combined for an overall study.

In Conclusion

It is impossible to typify fitness criteria in cases of spinal lesion, except for a few obvious cases. The approach which we have just outlined reflects the current positions generally defended by specialists in various countries. These positions must always be adapted to the specific clinical and psychological case. Collaborating physicians, radiologists and surgeons should carefully weigh the risks incurred and faithfulness to the interests of the aircrew and the armed forces. The problem of fitness criteria will change over a period of time, since surgical advances and new aeronautical procedures must be taken into account.

Editors' Recommendations /95

The editors believe that spinal fractures occurring after ejection constitute an important chapter in aeronautic medicine, whose study should be pursued over the next few years. In actuality, the use of new equipment may modify some of the findings studied in detail in this report. It is hoped that in a few years a working group will resume study of these frequent injuries to fighter pilots.

-- We recommend the systematic performance of x-rays of the spine immediately after ejection, no matter what the symptomatology may be.

-- It would be desirable to formulate uniform selection criteria. In general, the editors consider a given number of slight abnormalities (spondylolysis, for example) to be compatible with ejection. Attention is drawn to the excessive severity of some fitness criteria.

-- It is our opinion that experimental studies should be pursued to obtain improved positioning of the pilot in the seat and to attempt to determine physiopathologenic mechanisms, especially in complex aircraft escape.

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